Appraising Human Impact on Watersheds: The Feasibility of Training Citizen Scientists to make Qualitative Judgments

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Citizen science often requires volunteers to perform low-skill tasks such as counting and documenting environmental features. In this work, we contend that these tasks do not adequately meet the needs of citizen scientists motivated by scientific learning. We propose to provide intrinsic motivation by asking them to notice, compare, and synthesize qualitative observations. We describe the process of learning and performing qualitative assessments in the domain of water quality monitoring, which appraises the impact of land use on habitat quality and biological diversity. We use the example of water monitoring because qualitative watershed assessments are exclusively performed by professionals, yet do not require specialized tools, making it an excellent fit for volunteers. Within this domain, we observe and report on differences in background and training between professional and volunteer monitors, using these experiences to synthesize findings about volunteer training needs. Our findings reveal that to successfully make qualitative stream assessments, volunteers need to: (1) experience a diverse range of streams, (2) discuss judgments with other monitors, and (3) construct internal narratives about water quality. We use our findings to describe how different technologies may support these needs and generalize our findings to the larger citizen science community.

General Terms: Citizen Science, Qualitative Assessment, Water Quality, Stream Monitoring
Additional Key Words and Phrases: Citizen Science, Expert Interviews, Qualitative Assessment Task, Water Quality Monitoring

1. INTRODUCTION

Citizen science is a form of crowdsourcing that allows volunteers to collaborate with researchers on scientific data collection and analysis [Bonney et al. 2009]. A long-term goal of environmental citizen science research is to engage local communities in “democratic ownership” of environmental projects to provoke large-scale habitat accountability and civic protection efforts [Riesch et al. 2013].

Literature suggests that many citizen scientists are engaged and motivated by science-based learning and discovery [Raddick et al. 2009], but high training costs and limited resources often result in volunteers participating in only unskilled work. While practical, tasking volunteers with unskilled work can lead to complications, including boredom and disengagement [Flow 1990; Kiili et al. 2014], which may decrease data quality and participant retention [Eberbach and Crowley 2009]. Citizen science work is often comprised of unskilled tasks such as documenting, counting, identifying, classifying, and transcribing environment features [Bowser 2016; Wiggins 2013; Cohn 2008; Raddick et al. 2009; Crowston 2017; Eveleigh et al. 2014]. Instead of providing scientific education or increasing the required skill, projects may engage community members through gamification [Bowser et al. 2013] and novelty [Jackson et al. 2016].

Engaging citizen scientists in substantive, high-level tasks has potential to improve data quality and participant retention [Striner and Preece 2016; Wiggins et al. 2011]. This paper proposes engaging those citizen scientists motivated by learning goals with qualitative assessments—high-level assessment tasks focused on naturalistic, induc-
tive interpretations of an environment [Patton 2002; Denzin and Lincoln 2011]. A traditional barrier to assigning high-skill tasks to volunteers is that developing the required skills is difficult and time consuming. Qualitative assessments are usually made by professionals who learn through iterative personal experiences. Learning to make qualitative assessments requires access to a variety of heterogeneous environments, which is not practical for volunteers.

Recent advances in immersive technologies, 360° panoramic videos, augmented reality (AR), and virtual reality (VR) have effectively been able to recreate physical environments necessary for training with minimal cost [Cummings and Bailenson 2016; Ahn et al. 2014]. These virtual environments allow learners to experience several diverse environments in a short period of time. Our research thus considers the feasibility of training citizen scientists to make qualitative assessments using these technologies.

We situate our research in water monitoring for four reasons: (1) a standard protocol is used by many monitoring groups [Pond 2017], (2) assessments are exclusively made by professionals, (3) assessment does not require specialized tools, making it an ideal task for volunteers, and (4) assessment relies on first-hand experiences at stream sites, which immersive technology has the power to recreate. We consider the need for and feasibility of training citizen scientists to make qualitative assessments of streams and watersheds using a Rapid Bioassessment Protocol (RBP) [Barbour et al. 1999] which was developed by the Environmental Protection Agency (EPA) and is used nationally.

This work proposes training volunteers to make qualitative assessments, which intrinsically motivate investigators by asking them to notice, compare, and synthesize their observations. To accomplish this objective, we observe and report on differences in background and training between professional and volunteer monitors, using these experiences to synthesize findings about volunteer training needs. Our findings reveal that to successfully make qualitative stream assessments, volunteers need to: (1) experience a diverse range of streams, (2) discuss judgments with other monitors, and (3) construct internal narratives about water quality. Using these findings, we discuss how 360° videos, AR, and VR may be able to support this qualitative learning task, and generalize our findings to the broader citizen science community.

In summary, our contribution: (1) proposes training citizen scientists to make qualitative assessments to motivate volunteers, (2) describes how experts learn to make qualitative assessments of streams, and compares their learning process to volunteer experiences, and (3) describes how 360° videos, AR, and VR may help support qualitative assessment training.

2. BACKGROUND

We provide our operating definition of qualitative judgments and an overview of how they are learned and performed, with specific attention to water monitoring and the EPA Rapid Bioassessment Protocol.

2.1. Qualitative Judgments

Qualitative judgments are intuitive representations of mental models that scaffold the way people speak, listen, and interpret the world around them. In this paper, we define making qualitative judgments as using intuitive heuristics [Gilovich et al. 2002] to discern relationships between latent variables. Researchers often use these contextual judgments to describe and evaluate knowledge that is difficult to teach and evaluate procedurally [Perreault and Leigh 1989].

Making qualitative judgments requires evaluators to scaffold knowledge into internal cognitive maps, which chunk interconnected ideas into concepts and models that help them notice, compare, and identify patterns [Warren 2005]. Over time, this scat-
fold is shaped by experiential learning [Kerfoot 2003; Hmelo-Silver et al. 2007], cyclically fashioned together from multimodal and multisensory information [Haverkamp 2001], and from discussion, which is interpreted, and interwoven into previous experience [Young 2017].

Making qualitative judgments is difficult and often reserved for professionals. For instance, clinical psychiatrists recommend medical treatments based on qualitative assessments of patient conditions [Pomerantz 2016], and neurologists use qualitative assessments to characterize patient pain [Morse 2015]. Similarly, trainers use qualitative methods to evaluate athlete performance [Knudson 2013], and voice teachers use qualitative pedagogical techniques to diagnose vocal problems [McKinney 1994].

Scientists likewise use qualitative heuristics to understand nature. For instance, climate scientists use qualitative “climate proxies,” like perennial cherry blossom bloom periods, to assess the cumulative effect of climate change on changes in temperature or rainfall [Striner and Borovikov 2017]. Likewise, paleoecologists use fossil and sediment proxies to interpret and reconstruct ecosystems and environmental conditions of the past [Birks et al. 2011]. On a larger scale, astronomers pair qualitative heuristics with quantitative analyses to understand the conditions of unusual cosmic phenomena. For instance, astronomers draw conclusions about supernovae composition using heuristic interpretations of Hubble telescope images of scattered light echoes [Rest et al. 2008].

2.2. Learning to Make Qualitative Judgments

In the natural sciences, learning to make qualitative judgments consists of (1) noticing and observing phenomena, (2) comparing observations to expectations, (3) synthesizing observations into patterns, (4) scaffolding patterns into a cognitive map [Eberbach and Crowley 2009], and (5) updating the cognitive map using new information. First, learners notice phenomena, and make observations; this requires them to know when to ask questions, and what question to ask (e.g., “what thing am I looking at?”). Learners then synthesize patterns by comparing observations to internal webs of information [Alberdi et al. 2000], and recognizing similarities and differences [Crossan et al. 1999]. Finally, learners scaffold observations into an internal cognitive map, and iteratively update the map by making new observations [Kerfoot 2003]. Learners also update their cognitive map through discussion, which helps them form shared interpretation of meaning through metaphors, which allow them to transfer information between familiar and new domains [Crossan et al. 1999].

Teaching qualitative judgments is often challenging because experiences are subjective and difficult to surface, examine, compare, and explain [Crossan et al. 1999]. In the examples above, professionals learn to make assessments through experiential learning; they make observations and identify patterns by iteratively getting feedback from patients and students. Unlike professionals who learn from feedback loops, researchers learn to make intuitive judgments by studying related quantitative and qualitative data; for instance, in the astronomy example above, quantitative data about how light scatters helps astronomers visually interpret low resolution telescope images.

Professionals are able to make qualitative judgments because they have more experience—however, with enough experience, amateurs, too, are able to learn to make effective qualitative assessments. For instance, amateur bakers often use qualitative assessments to “troubleshoot” finicky recipes [Mimi 2018]. Similarly, successful amateur investors often use intuitive heuristics to “predict” company valuations and stock market changes [Roberts 1959].
2.3. Qualitative Judgments in Stream Monitoring

Stream ecology groups perform qualitative stream monitoring and assessment to report on the balance between development and environmental protection. For instance, the Maryland Department of Natural Resources uses monitoring to benchmark long term stream quality trends, examine impact of land use on habitat quality and biological diversity, and assess cumulative impacts to streams [Roth and Davis 2002]. Ecology groups also use data from monitoring projects to advocate for land use that protects regional watersheds [Barbour et al. 1999].

To effectively protect watersheds, Roth and Davis [Roth and Davis 2002] describe the need for cost-effective solutions that inform the public about stream conditions and reduce sampling program costs. For this reason, training citizen scientist monitors may not only increase volunteer retention, but may also benefit water monitoring agencies by creating a free task force and engaging the public in water quality issues.

2.4. Using the EPA's Rapid Bioassessment Protocol (RBP)

Although many watershed monitoring protocols exist, this work focuses on the EPA's Rapid Bioassessment Protocol (RBP) [Barbour et al. 1999], a qualitative metric of stream conditions. The RBP is part of a larger monitoring process that includes several quantitative assessment measures. These include measuring pH and temperature, and counting fish and benthic macroinvertebrates, small animals that live among stones, sediments and aquatic plants, whose presence is indicative of stream quality [Barbour et al. 1999]. We focus on this protocol because it used by many monitoring groups [Pond 2017].

The RBP protocol is made up of 13 measures, described below. Each metric is assessed on a 10 or 20 point scale. An example metric, channel alteration, is shown in figure 4.

(1) Epifaunal substrate evaluates opportunity for insect colonization and fish cover
(2) Embeddedness of cobble and boulders in stream sediment appraises the surface area available to fish and macroinvertebrates for shelter and spawning
(3) Pool substrate characterization evaluates the mixture of stream bottom substrates
(4) Velocity depth combinations notes diversity of water velocity and depth patterns
(5) Variability of pool environments characterizes the diversity of stream pools
(6) Sediment deposition estimates sediment accumulation at the bottom of a stream
(7) Channel flow status describes the degree to which a channel is filled with water
(8) Channel alteration estimates the extent to which a stream's shape has been altered
(9) Frequency of riffles and bends, judges the heterogeneity of a stream's shape
(10) Channel sinuosity evaluates the curvature of the stream
(11) Bank stability considers the extent to which banks have eroded
(12) Bank vegetation protection values the quality of vegetation protecting the stream
(13) Riparian zone width delineates the vegetative buffer between a stream bank and runoff pollutants

3. METHOD

The goal of this work is to assess the viability of training citizen science volunteers to make qualitative assessments of streams and watersheds using the EPAs Rapid Bioassessment Protocol (RBP) [Barbour et al. 1999]. To compare current teaching methods employed by professionals and citizen science groups, the first author (1) observed and participated in RBP training and data collection with professional water monitors and with volunteers, (2) informally discussed water monitoring methods with ecologists, and (3) conducted semi-structured interviews with professional monitors.
3.1. Training and Data Collection

3.1.1. Professional RBP Training and Data Collection Process. The first author participated and observed water quality training with 4 professional water monitoring groups that included between 2 and 6 monitors. Each session lasted approximately 3 hours. Data collection took place at either 2 or 3 100-meter sites at different points of a stream.

In the larger teams, RBP assessment was paired with quantitative monitoring tasks. First, monitors measured the depth and velocity of the stream at different points and measured quantitative measures such as temperature and PH. Then, they noted the absence or presence of stream characteristics like bedrock, and clay, and tallied the number of woody debris and roots in and around the stream. In addition, they collected samples of fish and macroinvertebrates.

During each session, the first author observed how monitors made RBP qualitative assessments. Monitors first made personal evaluations, then compared their evaluations with a partner or group members, and settled on a numeric assessment for the metric. Monitors did this for all 13 RBP measures, then totaled them into an overall score. As well as observing professional monitors, the first author had to chance to experience their learning process firsthand; they made RBP assessments alongside other monitors, learned through group discussions, and performed assessments as part of a group (figure 1).

![Fig. 1. left: A photo of the first author learning to make assessments. Right: A group of water biologists discussing their observations and EPA protocol assessments.](image)

3.1.2. Volunteer Training and Data Collection. The first author also observed and participated in volunteer RBP training. Unlike professionals, who learn onsite, monitors were introduced to the protocol through a 3 hour PowerPoint lecture [Wiss 2014] with images that exhibited a range of quality for the RBP stream characteristics (figure 2).

As well as experiencing PowerPoint training, the first author participated in a 3 hour outdoor training and data collection experience (figure 3) with 10 volunteer monitors. During data collection, monitors collected macroinvertebrates with hand-held fishing

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1 Although volunteers do not make qualitative assessments during data collection, they are introduced to the RBP scales as a background to water monitoring.
nets, separated them by species using a field guide, and counted them. After categorizing and tallying each species, volunteers practiced measuring the stream's PH and temperature.

Fig. 3. Images from the volunteer outdoor data collection. During data collection, volunteers collected and counted macroinvertebrates, measured PH and temperature.

3.2. Informal Discussions with Ecologists
We received initial insights about the qualitative stream assessment process at the Association of Mid-Atlantic Aquatic Biologists (AMAAB), a regional conference for wa-
ter biologists and ecologists. During the conference, the first author presented a poster describing early findings based on the in-person training experiences. During the 2 hour poster session, the author discussed her findings with more than 15 ecologist, biologists, and water monitors. They also collected feedback on how the RBP protocol was employed by different monitoring groups, how her first-person training experiences compared to researchers' own training, and whether volunteers could be trained virtually to perform these tasks.

3.3. Semi-Structured Interviews with Professional RBP monitors
We conducted 5 in-depth interviews with professional monitors by phone or in person (after on-site training), each of which lasted approximately 1.5 hours. Participants included an aquatic biologist at the EPA, a program manager of the the Virginia Department of Environmental Protection, and an ecologist at the Fairfax Department of Public Works and Environmental Services. Interviewees had between 2 and 23 years of experience making qualitative stream assessments, including one participant who helped develop and test the protocol in 1992. During each interview, participants described (1) their personal process for making RBP assessments, (2) how they learned to make assessments, and (3) how they taught young professionals to make assessments. In addition, we conducted an interview with the water quality monitoring program coordinator at at the Audubon Naturalist Society [Mathias] to understand the nature of volunteer water monitoring tasks and training.

Several interview and feedback sessions were audio-recorded, however recording was not possible for all sessions, either due to a loud outdoor environment or a conference setting. When recording was not possible, the first author took detailed notes and followed up with participants for further discussion and clarification. We then listened to recordings, and transcribed important quotes. We chose not to transcribe recordings in their entirety because of budget and time constraints. However, we accounted for this by taking detailed notes during the interviews, intermittently stopping interviewees to repeat important words or phrases.

3.4. Data Analysis
We compiled notes, annotations, and quotes from the training and data collection experiences, informal discussions, and expert interviews into a single spreadsheet, and thematically open-coded important themes [Strauss et al. 1990]. Our open-coding process took several stages of iteration. First we split the notes, annotations, and quotes into individual statements. Then, we color-coded related statements, grouped them into categories, and ascribed a theme name to each category (this process was similar to performing thematic analysis by grouping color-coded post-it notes [Braun and Clarke 2006]). We then iterated on the categories by regrouping statements until we felt that they fit together cohesively. As we reorganized the statements, we renamed the category themes to most closely fit the patterns we observed. Once we were satisfied with our precise themes, we grouped related themes together, and identified a final set of themes and sub-themes.

4. RESULTS
The following section compares current teaching methods employed by citizen science groups and professional water monitors, and describe challenges of making qualitative stream assessments. Then, we describe salient themes from expert interviews and feedback sessions.
4.1. Differences in Background

We found that the professional monitors we met had a more extensive background in the natural sciences than the volunteers. All the professional monitors we interviewed either had a degree or had taken multiple courses in biology, ecology or conservation before focusing on water monitoring. In addition, professionals mentioned completing water-quality accreditations or certificates to learn to perform procedural tasks like fish and macroinvertebrate sampling. Although they had related training, the professionals we spoke to did not have a specific background in RBP assessment, they learned to do the qualitative assessment through their first-person experiences.

In contrast to professionals, volunteers that participated in water monitoring training and data collection had a range of background experiences: some had degrees in biology or ecology, others had participated in other monitoring training, and a few had little to no experience in the domain, but were eager to learn. Notably, almost all of the volunteer monitors we spoke to during the citizen science outdoor training session had some sort of higher education background: several of the younger volunteers were recently out of college, and many of the older volunteers were retired educators. We do not have exact data on volunteer backgrounds because we learned about them informally, through conversations during outdoor data collection. However, finding that volunteers were highly educated is supported by previous work suggesting that citizen science attracts affluent volunteers motivated to improve society [Raddick et al. 2009].

In addition, the Audubon society coordinator discussed several background courses that helped support volunteers with different backgrounds. Volunteers could learn about ecology through courses like a natural history of aquatic ecology and healthy stream biology. Likewise, volunteers could build procedural and identification skills through classes such as an overview of invasive plants and a series on aquatic insect identification [Mathias]. Volunteers could even take certification exams to participate in certain projects or lead volunteer teams.

While professional monitors had more formal training than volunteers, a surprising finding is that there was less of a distinction between professional and volunteer monitoring backgrounds than we anticipated. Both groups had a higher education, had some experience in the natural sciences, and had opportunities to become better monitors through certifications. Notably, the biggest difference between professionals and volunteers was the number of streams each group had experience evaluating; professionals visited many more streams than volunteers, and were thus able to more easily compare them.

Since professional monitors had the opportunity to first-hand experience many more streams than volunteers, the way they learned about the qualitative RBP measures differed greatly from volunteers. Professionals learned to make assessments in an apprenticeship under more experienced monitors, whereas volunteers learned about the measures through a PowerPoint lecture that outlined the protocol measures, but did not transfer any nuanced or practical assessment skills.

4.2. Challenges Interpreting Qualitative Measures

As well as finding differences in background and learning between professional and volunteer monitors, our research uncovered multiple challenges in interpreting the protocol. The task of interpreting a protocol is quite similar in nature to interpreting a survey question; in order to make an informed response, a participant has to understand the meaning of the words in the question, understand the scale dimensions, and know how to map the question to the scale [Fowler 1995]. Similarly, in order to make an informed RBP assessment, an evaluator has to understand the contextual defini-
tions of quality defined by each protocol metric, then consider what quality attributes correspond to scales values.

A primary challenge of the RBP is characterizing the state of an outdoor environment using a quasi-quantitative scale. To make an informed assessment, monitors must make subjective interpretations of multiple scale descriptions that are hard to quantify. Table I illustrates several interpretation issues that exist, including interpreting scale measures, accounting for site variability, evaluating related measures, and interpreting and accounting for the passage of time.

For instance, during a professional training session, monitors explained that a scale measuring embeddedness of particles in a stream bed (RBP protocol 2a [Barbour et al. 1999]) should not be interpreted linearly, even though it was written to suggest linearity: the written scale suggests that 25% is suboptimal quality and 75% is poor quality. Professional monitors explained that realistically, more than 25% embeddedness should be characterized as poor quality because the environment becomes unsuitable for macroinvertebrates. Given this discrepancy, it is would not be clear to a volunteer monitor whether to evaluate 25% embeddedness as suboptimal or poor.

Similarly, some protocol measures describe quality using time measures that require application of heuristics. For example, in channel alteration (RBP protocol 6, shown in figure 4, the suboptimal condition asks monitors to evaluate if there is evidence of channelization (stream straightening, widening or deepening) “greater than past 20 years.” This assumes that monitors can heuristically estimate the timeframe of a disturbance. Further, this time measure is used asymmetrically, only to describe the suboptimal category. This increases the challenge of making evaluations because it is difficult to compare the suboptimal category to other categories.

Our experiences found that the subjectivity and imprecision of the RBP protocol compelled monitors to rely background knowledge and personal experiences to make assessments. Notably, our informal conversations with ecologists revealed that the water monitoring community was aware of interpretation challenges that existed in the protocol and made up for the protocol flaws with personal contextual knowledge.

Although they heavily relied on personal experiences, professionals suggested that their divergent monitoring experiences biased their assessment. For instance, an ecologist in Fairfax, Virginia worked with primarily urban disturbed streams, whereas a West Virginia monitor evaluated undisturbed rural streams. Due to their different backgrounds, the Fairfax ecologist was more likely to judge stream quality more leniently than the West Virginia monitor.

In line with these discrepancies, Roth [Roth and Davis 2002] remarks that the monitoring community must resolve issues in field sampling protocols, differences in types of data collected, and discrepancies in condition ratings. Further, Roth appeals for increased accuracy of stream condition estimates.

4.3. Expert Interview Findings

As well as revealing the nature of professional monitoring experiences, the expert interviews uncovered multiple themes that illuminate professionals’ qualitative assessment process. These themes help us understand how monitors make observations in outdoor stream environments, how they compare streams, identify patterns, and use these patterns to make RBP assessments.

4.3.1. Making Intuitive Judgments of Quality. Our expert interviews revealed that professional monitors had a complex relationship with the RBP protocol. Professionals suggested that together, the 13 measures helped capture “a snapshot” of stream quality, but many agreed that the individual measures were either imprecise and challenging to interpret. This supports the first authors experience learning to make RBP assess-
The RBP protocol suggests that measures should be assessed linearly, but professionals suggest linearity varies between measures. For example, professionals interpret a stream with 25% or more embeddedness as poor because the environment is unsuitable for macro-invertebrate organisms even though the protocol considers the habitat suboptimal.

Data collectors are asked to evaluate 100 meter stream cross sections, but how should users evaluate areas containing with significant variability? Professionals make holistic judgments of quality based using their experience, but new data collectors have no foundation with which to make such judgments.

Several measures of stream quality directly affect one another (e.g. stream bank stability affects sediment deposits). How should data collectors account for this in their assessments?

3 of 10 protocol measures ask users to evaluate transience of stream elements (e.g. logs and cobble) and recency of human activity (e.g. whether stream channel alteration occurred more or less than 20 years ago). How would users know how to judge the passage of time?

| Protocol Interpretation Challenges | Example |
|-----------------------------------|---------|
| How to interpret scales?          | The RBP protocol suggests that measures should be assessed linearly, but professionals suggest linearity varies between measures. For example, professionals interpret a stream with 25% or more embeddedness as poor because the environment is unsuitable for macro-invertebrate organisms even though the protocol considers the habitat suboptimal. |
| How to Account for Site Variability? | Data collectors are asked to evaluate 100 meter stream cross sections, but how should users evaluate areas containing with significant variability? Professionals make holistic judgments of quality based using their experience, but new data collectors have no foundation with which to make such judgments. |
| How to evaluate related measures? | Several measures of stream quality directly affect one another (e.g. stream bank stability affects sediment deposits). How should data collectors account for this in their assessments? |
| How to interpret passage of time?  | 3 of 10 protocol measures ask users to evaluate transience of stream elements (e.g. logs and cobble) and recency of human activity (e.g. whether stream channel alteration occurred more or less than 20 years ago). How would users know how to judge the passage of time? |

Table I.

| Condition Category | Optimal | Suboptimal | Marginal | Poor |
|--------------------|---------|------------|----------|------|
| Channelization or dredging absent or minimal; stream with normal pattern. | Some channelization present usually in areas of bridge abutments; evidence of past channelization, i.e., dredging, greater than past 20 yr may be present, but recent channelization not present | Channelization may be extensive; embankments or shoring structures present on both banks; and 40 to 80% of stream reach channelized and disrupted. | Banks shored with gabion or cement; over 80% of the stream reach channelized and disrupted. Instream habitat greatly altered or removed entirely. |

Fig. 4. *Channel Alteration*, a qualitative EPA metric that evaluates human impact on stream channels. This metric poses several challenges, including asking monitors to interpret the meaning of "normal pattern" streams and subjective time metrics (e.g. "greater than the past 20 years"), and to judge percentages of channel disturbance.
ments with professional monitors, and parallels our informal discussions with professionals.

We found that professionals with different amounts of expertise make RBP assessments very differently; less experienced monitors dutifully tried to interpret the protocol language, whereas more experienced professionals developed an intuition for assessment quality. Two interviewees, a senior biologist and ecologist, said they linked “mental images” from their experiences to the protocol scales. Likewise, the program manager who helped develop the protocol suggested that after making evaluations for 24 years, they could evaluate a stream at a glance, “without even scoring it.” While the RBP scales are technically quantitative, expert interviews confirmed our theory that practically, the measures are qualitative.

4.3.2. Using Multisensory Information to Make Judgments. The professionals we interviewed and the ecologists we spoke to at the AMAAB conference described using multisensory environmental information to form opinions of a stream’s quality. Several biologists mentioned supplementing the EPA protocol with additional measures for trash, presence of human activity, and invasive plant and animal species. For instance, an ecologist commented that hearing European Starlings (an invasive species) was indicative of poor stream quality. Likewise, another noted that invasive plant species often indicated that a stream habitat has probably been disturbed. Although these heuristics were not formally part of the qualitative assessment protocol, professionals suggested that paying attention to these characteristics helped them locate environment stressors that affected the RBP measures.

Professional monitors also used ambient sensory information to take note of habitat stressors during observations. For example, one ecologist approximated the strength of stream riffles by the sound of rushing water, whereas another used sun warmth and wind strength to judge the density of stream bank vegetation. Since formal assessment was limited to 100 meter cross-sections, monitors conferred that additional sensory information allowed them to make more comprehensive observations about the state of the stream that they may not have readily been able to see. This is in-line with Dedes 1999 findings [Dede et al. 1999] that multisensory information helps students understand complex scientific models through experiential metaphors and analogies. This is likewise in line with Dedes (2017) [Dede et al. 2017] work on stream identification tasks, finding that sensory information (e.g. sound, color and turbidity of the water, weather variables, shifts in grass color) could help learners sense pattern changes.

4.3.3. Describing Stream Quality using Past, Present, and Future Narratives. As well as observing sensory information and making intuitive judgments, several monitors we spoke to actively interpreted ‘narratives’ of the stream spaces: how the landscape had transformed from the past, and how the stream in its present state would shape its future. For instance, during an on-site learning experience at a stream in northern Virginia, a professional monitor pointed to markers indicating that a stream was part of a historical agriculture site. They explained that the former use of the land had caused extensive erosion at the monitoring site by irrigating water through the stream, causing faster moving water that wore away at the streams banks. Using the streams history and current state, the professional then predicted that in the next 5-10 years the stream would become wider and more eroded.

Likewise, during an expert interview, a biologist emphasized how connected the ecosystem was, and described the stream landscape as a consequence of multiple events. They recounted that sedimentation was often causes by people mowing a streams vegetative zone in order to keep snakes off of their property. Then they explained that removing bank vegetation removes the roots holding soil in place, and that the next time a stream floods, the whole bank erodes. Rather than merely evalu-
ating streams in their current forms, professional monitors predicted what caused the stream characteristics, and how those stream characteristics would change over time.

5. DISCUSSION
The goal of this work was to assess the viability of training citizen science volunteers to make qualitative assessments of streams and watersheds using the EPAs Rapid Bioassessment Protocol (RBP) [Barbour et al. 1999]. We aimed to do this by examining the challenges of interpreting the RBP, and discerning between professionals and volunteer water monitor experiences.

Our findings suggest that the biggest difference between professional and volunteer monitors are volunteers’ lack of experience with on-site streams; professionals experience many different streams throughout their career, whereas volunteers only see a handful of streams, likely in their immediate neighborhood or community.

Although we did not formally interview volunteers about their experience evaluating streams, our findings suggest that professionals use their vast experience to make intuitive judgments of streams that extend beyond RBP measures: they make intuitive judgments of quality, interpret stream characteristics using multisensory information, and are able to describe past, present, and future narratives of different streams. That professional monitors make intuitive judgments can be at least partially explained by the challenges of making qualitative assessments using the RBP: the protocol asks professionals to subjectively interpret differences in quality based on their experiences and to account for misleading measures.

5.1. Volunteer Training Needs
Professionals develop intuitive judgments by visiting many streams of differing quality. In order for volunteers to be able to skillfully interpret the RBP, they too would need to experience first-hand a range of diverse streams. Further, our findings suggest that professionals scaffold their intuitive knowledge through environmental sensory information. Volunteers may also need to experience this environmental information to develop similar intuitive judgments of quality. This confirms findings from Psotka [Psotka 1995] and Dihn [Dinh et al. 1999], who suggest that multisensory cues can reduce conceptual load, create salient memories and emotional experiences, and increase memory and sense of presence for environmental information.

Our findings also suggest that the process of discussing and reviewing intuitive judgments with peers helps professionals review and update their internal information scaffold, which is in line with Crossan’s work on creating shared interpretations of meaning [Crossan et al. 1999]. Effective training should thus include some sort of assessment loop, allowing learners to discuss and receive feedback from peers or teachers.

Finally, our work found that rather than making isolated assessments, many professionals interpret the state of a stream as part of a changing narrative. This suggests that professionals develop higher-order thinking skills, inductively envisioning the stream’s history and future based on their knowledge of how stream features affect one another. This finding strongly echoes the literature; climate scientists use qualitative heuristics to monitor change over time, whereas paleoecologists use qualitative heuristics to reconstruct the past. This is also in line with Bloom’s education taxonomy [Krathwohl 2002], which suggests that beyond analyzing and evaluating information, students should be able to reassemble information into new ideas. To become effective monitors, learners must be trained to consider how environmental features together impact stream characteristics over time.
### Table II.

| Technology             | Affordances                                                                 | Drawbacks                                                 |
|------------------------|-----------------------------------------------------------------------------|------------------------------------------------------------|
| 360° Panoramic Videos  | — Flexible viewing modalities                                               | — Minimal interaction                                       |
|                        | — Cheap to view on an HMD                                                   | — Expensive to produce                                     |
|                        | — Real video footage                                                        | — Requires careful video calibration                       |
| Augmented Reality (AR) | — Interact with the real world                                               | — Imprecise visual rendering                               |
|                        | — Maintain environmental awareness                                          | — Expensive to develop                                     |
|                        |                                                                           | — Expensive to deploy                                      |
|                        |                                                                           | — Poor support for multi-user experiences                   |
| Virtual reality (VR)   | — Sense of presence in virtual worlds                                       | — Can cause simulator sickness                              |
|                        | — Interact with many environments in same location                          | — Expensive to develop                                     |

#### 5.2. Training Solutions

Our findings suggest that volunteers need to experience streams the way that professionals do, and to learn from peers and experts. However, citizen science training is often constrained by time and monetary resources [Bonney et al. 2009; Wiggins 2013]; personally training a crowd of volunteers at several streams is infeasible and unrealistic. Recent advances in 360° panoramic videos, augmented reality (AR), and virtual reality (VR) have made it possible to remotely give learners the experience of evaluating different streams, and getting feedback from peers or experts. While it is not in the scope of this paper to compare their value, the following sections describe each technology, and table II summarizes the affordances and drawbacks of each.

#### 5.2.1. Panoramic Videos

360° videos are spherical video recordings that record every direction around a camera. Viewers can playback video either on a flat display by controlling panoramic viewing direction, or by projecting the panorama onto a series of projectors or in a head mounted display (HMD) [Garza 2015]. 360° videos are easy to view on any computer or cheap smartphone HMD such as Google Cardboard. Likewise, 360° videos are realistic, since they capture actual stream footage. Although easy to view, high quality videos can be expensive to produce, since they require either a special rig of multiple cameras or a dedicated camera that simultaneously films overlapping angles. Further, to create the 360° effect, footage must be carefully stitched and calibrated [Butler et al. 2011]. In addition, the videos only allow users to change the panorama view, but do not support support interaction with the environment.
5.2.2. Augmented Reality (AR). AR is a direct or indirect live view of a real-world environment “augmented” by computer-generated perceptual information. Overlaid information can be constructive (i.e. additive to the natural environment) or destructive (masking of the environment) and is spatially perceived as an aspect of the real environment [Van Krevelen and Poelman 2010]. Although spatially realistic, AR is expensive to develop because development kits are still in their infancy. Further, AR often struggles with imprecise visual rendering, and does not support multi-user experiences [Van Krevelen and Poelman 2010].

5.2.3. Virtual Reality (VR). VR is a computer-generated scenario that simulates physical experiences [Ult.]. The immersive environment can be similar to the real world or it can be fantastical, creating an experience not possible in our physical reality. VR allows users to look around, move within, and interact with an artificial world. Current technologies pair the VR experiences with realistic images, sounds, and sensations. VR’s sense of presence in a virtual world allows users to interact with different environments, features, and people in any location [Dalgarno and Lee 2010], however, development is expensive and time-consuming. Further, may cause participants to develop temporary simulator sickness [Kennedy et al. 1993].

The technologies described offer distinct benefits for qualitative training, but also suffer from distinct challenges. For instance, 360° video offer high realism and cheap deployment, but is not interactive. In contrast, AR offers realism and interactivity, but suffers from lack of precision. Relative to 360° videos and AR, VR creates the greatest sense of presence and interaction in any number of virtual worlds, but is not photorealistic.

5.3. Future Work

Future work should consider which tools most easily allow learners to flexibly and cheaply experience a range of environments. To do this, we plan to rigorously weigh the affordances and drawbacks of 360° videos, AR, and VR against the volunteer training needs we identified earlier in the discussion, and identify whether one technology is most effective for training.

In order to select the most appropriate technology, we must consider how to implement training that addresses the high-level volunteer needs we identified. For instance, we found that volunteers need to experience different stream environments, but it is not clear what kind of realism they need in order to compare their observations and synthesize them into patterns. Literature suggests that multisensory information improves learning and judgment tasks [Dematte et al. 2007; Brooks Jr et al. 1990; Lee and Spence 2008; Yannier et al. 2016], but it is not clear how much realism is necessary in training. Is photorealistic training necessary to scaffold experiences into an effective cognitive map? Likewise, is multisensory realism necessary?

Similarly, future work must consider how virtual training should support learner discussion and negotiation of meaning. Should training include discussion with peer learners, with professionals, or with both? Can peers or professionals be simulated with non-player characters (NPC’s), or must they be real people? If they are real, should peer learners or professionals interact symmetrically or asymmetrically with one another? To support discussion and negotiation of meaning, future work must also consider how to support joint action and coordination, which are built on the spatiotemporal coherency of a shared interaction space [Knoblich et al. 2011].

Finally, training design must consider how to help learners unite their stream quality observations with background knowledge to form stream quality narratives. Which tools support learners from a range of backgrounds? How might training be designed to help learners reassemble their stream observations into a temporal narrative?
6. CONCLUSION
The overarching goal of our work was to use the water monitoring domain to assess the viability of training volunteers to make different types of inductive qualitative assessments. To undertake this challenge, we used the domain of water monitoring to understand how professionals train and make qualitative assessments, and how volunteers learn about qualitative assessments. To do this, we observed and participated in RBP training and data collection with professional water monitors and with citizen scientists, informally discussed water monitoring methods with ecologists, and conducted semi-structured interviews with professional monitors.

We found that professionals learned to make assessments on-site, through iterative assessments and discussions with peers and instructors. From their experience, we found that professionals develop intuitive judgments of quality, use multisensory environmental information to make judgments, and construct past and future narratives of the stream using environmental characteristics. We also found that the qualitative RBP protocol is subjective and misleading, perhaps because it tries to characterize intrinsically qualitative measures.

Contrary to our expectations, we found that volunteers primarily differed from professionals in the number of streams they had visited and assessed. To match professional training experiences, we identified 3 training needs; to first-hand experience environmental information in order to develop intuitive judgments, to discuss judgments with other monitors, and to form quality narratives from assessments.

6.1. Generalizing to other Domains
While our work focused on the domain of water monitoring, our findings inform other ecology citizen science projects like eBird, IceWatch, and the Clean Air Coalition, which assess physical, ecological, and societal variables [McKinley et al. 2017]. A goal of these projects is to help the public understand and appreciate complex ecosystems, and to engage them in the task of identifying problems and solutions. Training citizen scientists to interpret qualitative measures related to these projects could help support this goal. For instance, birdwatchers could learn to assess ecosystem habitats based on the presence of different types of birds. Likewise, ice and pollution monitors could learn to identify relationships between observable and climate factors. Paired with quantitative measures, learning to make qualitative assessments can help volunteers understand and appreciate complex relationships that comprise their world.

ELECTRONIC APPENDIX
The electronic appendix for this article can be accessed in the ACM Digital Library.

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REFERENCES
The Ultimate Virtual Reality Technology Guide. (????), [http://www.realitytechnologies.com/virtual-reality](http://www.realitytechnologies.com/virtual-reality)
Sun Joo Grace Ahn, Jeremy N Bailenson, and Dooyeon Park. 2014. Short-and long-term effects of embodied experiences in immersive virtual environments on environmental locus of control and behavior. *Computers in Human Behavior* 39 (2014), 235–245.
Eugenio Alberdi, Derek H Sleeman, and Meg Korpi. 2000. Accommodating surprise in taxonomic tasks: The role of expertise. *Cognitive Science* 24, 1 (2000), 53–91.
Michael T Barbour, Jeroen Gerritsen, Blaine D Snyder, and James B Stribling. 1999. Rapid bioassessment protocols for use in wadeable streams and rivers. *Periphyton, Benthic Macroinvertebrates, and Fish (2nd edn). US Environmental Protection Agency, Office of Water, Washington, DC EPA* (1999).
H John B Birks, Oliver Heiri, Heiki Seppä, and Anne E Bjune. 2011. Strengths and weaknesses of quantitative climate reconstructions based on late-Quaternary biological proxies. *Open Ecology Journal* 3, 1 (2011), 68–110.

ACM Journal Name, Vol. V, No. N, Article A, Publication date: January YYYY.
Rick Bonney, Caren B Cooper, Janis Dickinson, Steve Kelling, Tina Phillips, Kenneth V Rosenberg, and Jennifer Shirk. 2009. Citizen science: a developing tool for expanding science knowledge and scientific literacy. *BioScience* 59, 11 (2009), 977–984.

Anne Bowser, Derek Hansen, Yurong He, Carol Boston, Matthew Reid, Logan Gunnell, and Jennifer Preece. 2013. Using gamification to inspire new citizen science volunteers. In *Proceedings of the first international conference on gameful design, research, and applications*. ACM, 18–25.

Anne Elizabeth Bowser. 2016. Cooperative design, cooperative science: Investigating collaborative research through design with floracaching. Ph.D. Dissertation. University of Maryland, College Park.

Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative research in psychology* 3, 2 (2006), 77–101.

Frederick P Brooks Jr, Ming Ouh-Young, James J Batter, and P Jerome Kilpatrick. 1990. Project GROPE-Haptic displays for scientific visualization. In *ACM SIGGraph computer graphics*, Vol. 24. ACM, 177–185.

Alex Butler, Otmar Hilliges, Shahram Izadi, Steve Hodges, David Molyneaux, David Kim, and Danny Kong. 2011. Vermeer: direct interaction with a 360 viewable 3D display. In *Proceedings of the 24th annual ACM symposium on User interface software and technology*. ACM, 569–576.

Jeffrey P Cohn. 2008. Citizen science: Can volunteers do real research? *BioScience* 58, 3 (2008), 192–197.

Mary M Crossan, Henry W Lane, and Roderick E White. 1999. An organizational learning framework: From intuition to institution. *Academy of management review* 24, 3 (1999), 522–537.

Kevin Crowston. 2017. Gravity Spy: Humans, Machines and The Future of Citizen Science. In *Companion of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing (CSCW ’17 Companion)*. ACM, New York, NY, USA, 163–166. DOI: [http://dx.doi.org/10.1145/3022198.3026329](http://dx.doi.org/10.1145/3022198.3026329)

James J Cummings and Jeremy N Bailenson. 2016. How immersive is enough? A meta-analysis of the effect of immersive technology on user presence. *Media Psychology* 19, 2 (2016), 272–309.

Barney Dalgarno and Mark JW Lee. 2010. What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology* 41, 1 (2010), 10–32.

Chris Dede, Tina A Grotzer, Amy Kamarainen, and Shari J Metcalf. 2017. Virtual Reality as an Immersive Medium for Authentic Simulations. In *Virtual, Augmented, and Mixed Realities in Education*. Springer, 133–156.

Chris Dede, Marilyn C Salzman, R Bowen Loftin, and Debra Sprague. 1999. Multisensory immersion as a modeling environment for learning complex scientific concepts. In *Modeling and simulation in science and mathematics education*. Springer, 282–319.

M Luisa Dematte, Robert Osterbauer, and Charles Spence. 2007. Olfactory cues modulate facial attractiveness. *Chemical Senses* 32, 6 (2007), 603–610.

Norman K Denzin and Yvonna S Lincoln. 2011. *The Sage handbook of qualitative research*. Sage.

Huong Q Dinh, Neff Walker, Larry F Hodges, Chang Song, and Akira Kobayashi. 1999. Evaluating the importance of multi-sensory input on memory and the sense of presence in virtual environments. In *Virtual Reality, 1999. Proceedings., IEEE*. IEEE, 222–228.

Catherine Eberbach and Kevin Crowley. 2009. From everyday to scientific observation: How children learn to observe the biologist’s world. *Review of Educational Research* 79, 1 (2009), 39–68.

Alexandra Eveleigh, Charlene Jennett, Ann Blandford, Philip Brohan, and Anna L Cox. 2014. Designing for dabblers and deterring drop-outs in citizen science. In *Proceedings of the 32nd annual ACM conference on Human factors in computing systems*. ACM, 2985–2994.

Csikszentmihalyi Flow. 1990. *The psychology of optimal experience*. Harper&Row, New York (1990).

Floyd J Fowler. 1995. *Improving survey questions: Design and evaluation*. Vol. 38. Sage.

Frida Garza. 2015. With Google’s new immersive videos, you can feel what it’s like to be a ballet dancer. (Dec 2015). [https://qz.com/562697/with-gooles-new-immersive-videos-you-can-feel-what-its-like-to-be-a-ballet-dancer/](https://qz.com/562697/with-gooles-new-immersive-videos-you-can-feel-what-its-like-to-be-a-ballet-dancer/)

Thomas Gilovich, Dale Griffin, and Daniel Kahneman. 2002. *Heuristics and biases: The psychology of intuitive judgment*. Cambridge university press.

Michael Haverkamp. 2001. Application of Synesthetic Design as multi-sensory Approach on Sound Quality. (2001).

Cindy E Hmelo-Silver, Surabhi Marathe, and Lei Liu. 2007. Fish swim, rocks sit, and lungs breathe: Expert-novice understanding of complex systems. *The Journal of the Learning Sciences* 16, 3 (2007), 307–331.

Corey Brian Jackson, Kevin Crowston, Gabriel Mugar, and Carsten Osterlund. 2016. "Guess What! You're the First to See This Event": Increasing Contribution to Online Production Communities. In *Proceedings of the 19th International Conference on Supporting Group Work (GROUP '16)*. ACM, New York, NY, USA, 171–179. DOI: [http://dx.doi.org/10.1145/2957276.2957284](http://dx.doi.org/10.1145/2957276.2957284)
Appraising Human Impact on Watersheds

Robert S Kennedy, Norman E Lane, Kevin S Berbaum, and Michael G Lilienthal. 1993. Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. The international journal of aviation psychology 3, 3 (1993), 203–220.

Karlene Kerfoot. 2003. Learning intuition-less college and more kindergarten: The leader’s challenge. Dermatology Nursing 15, 6 (2003), 567.

Kristian Kiili, Timo Lainema, Sara de Freitas, and Sylvester Arnab. 2014. Flow framework for analyzing the quality of educational games. Entertainment Computing 5, 4 (2014), 367–377.

Günter Knoblich, Stephen Butterfill, and Natalie Sebanz. 2011. Psychological research on joint action: theory and data. In Psychology of learning and motivation. Vol. 54. Elsevier, 59–101.

Duane V Knudson. 2013. Qualitative diagnosis of human movement: improving performance in sport and exercise. Human kinetics.

David R Krathwohl. 2002. A revision of Bloom’s taxonomy: An overview. Theory into practice 41, 4 (2002), 212–218.

Ju-Hwan Lee and Charles Spence. 2008. Assessing the benefits of multimodal feedback on dual-task performance under demanding conditions. In Proceedings of the 22nd British HCI Group Annual Conference on People and Computers: Culture, Creativity, Interaction-Volume 1. British Computer Society, 185–192.

Mathias. (????). http://www.ansbookshop.org/index.php/water-quality-monitoring-program

Duncan C McKinley, Abe J Miller-Rushing, Heidi L Ballard, Rick Bonney, Hutch Brown, Susan C Cook-Patton, Daniel M Evans, Rebecca A French, Julia K Parrish, Tina B Phillips, and others. 2017. Citizen science can improve conservation science, natural resource management, and environmental protection. Biological Conservation 208 (2017), 15–28.

James C McKinney. 1994. The diagnosis and correction of vocal faults: a manual for teachers of singing and for choir directors (Revised ed.). Nashville: Genevox (1994).

Janice M Morse. 2015. Using qualitative methods to access the pain experience. British journal of pain 9, 1 (2015), 26–31.

Michael Q Patton. 2002. Qualitative research methods and evaluation. Methods, Sage, Thousand Oaks (2002).

William D Perreault and Laurence E Leigh. 1989. Reliability of nominal data based on qualitative judgments. Journal of marketing research 26, 2 (1989), 135.

Andrew M Pomerantz. 2016. Clinical psychology: Science, practice, and culture. Sage Publications, Chapter 7, 151–181.

Greg Pond. 2015-2017. Personal Communication. Environmental Protection Agency.

Joseph Psotka. 1995. Immersive training systems: Virtual reality and education and training. Instructional science 23, 5-6 (1995), 405–431.

M Jordan Raddick, Georgia Bracey, Pamela L Gay, Chris J Lintott, Phil Murray, Kevin Schawinski, Alexander S Szalay, and Jan Vandenberg. 2009. Galaxy zoo: Exploring the motivations of citizen science volunteers. arXiv preprint arXiv:0909.2925 (2009).

Armin Rest, DL Welch, NB Suntzeff, L Oester, H Lanning, K Olsen, RC Smith, AC Becker, M Bergmann, P Challis, and others. 2008. Scattered-light echoes from the historical galactic supernovae Cassiopeia A and Tycho (SN 1572). The Astrophysical Journal Letters 681, 2 (2008), L81.

Hauke Riesch, Clive Potter, and Linda Davies. 2013. Combining citizen science and public engagement: the Open AirLaboratories Programme. JCOM 12, 3 (2013), A03.

Harry V Roberts. 1959. Stock-Market Patterns And Financial Analysis: Methodological Suggestions. The Journal of Finance 14, 1 (1959), 1–10.

Nancy E Roth and Wayne S Davis. 2002. Biological indicator variability and stream monitoring program integration: a Maryland case study. US Environmental Protection Agency.

Anselm Strauss, Juliet Corbin, and others. 1999. Basics of qualitative research. Vol. 15. Newbury Park, CA: Sage.

Alina Striner and Anna Borovikov. 2017. Embodied VR Experience to Help Non-Scientists Experience the Subtle, Gradual and Cumulative Nature of Climate Change. (Mar 2017).

Alina Striner and Jenny Preece. 2016. StreamBED: Training citizen scientists to make qualitative judgments using embodied virtual reality training. In Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems. ACM, 1201–1207.

DWF Van Krevelen and Ronald Poelman. 2010. A survey of augmented reality technologies, applications and limitations. International journal of virtual reality 9, 2 (2010), 1.
Ian Warren. 2005. Teaching patterns and software design. In Proceedings of the 7th Australasian conference on Computing education-Volume 42. Australian Computer Society, Inc., 39–49.

Andrea Wiggins. 2013. Free as in puppies: compensating for ICT constraints in citizen science. In Proceedings of the 2013 conference on Computer supported cooperative work. ACM, 1469–1480.

Andrea Wiggins, Greg Newman, Robert D. Stevenson, and Kevin Crowston. 2011. Mechanisms for Data Quality and Validation in Citizen Science. In Proceedings of the 2011 IEEE Seventh International Conference on e-Science Workshops (E-SCIENCEW ’11). IEEE Computer Society, Washington, DC, USA, 14–19. DOI:http://dx.doi.org/10.1109/eScienceW.2011.27

Cathy Wiss. 2014. How to Read Your Stream. Maryland Audubon Society. http://md.audubon.org/

Nesra Yannier, Scott E Hudson, Eliane Stampfer Wiese, and Kenneth R Koedinger. 2016. Adding Physical Objects to an Interactive Game Improves Learning and Enjoyment: Evidence from EarthShake. ACM Transactions on Computer-Human Interaction (TOCHI) 23, 4 (2016), 26.

Scott Young. 2017 (accessed February 2, 2017). Holistic Learning (e-book). http://www.scottheyoung.com/blog/Programs/HolisticLearningEBook.pdf