AN ABSTRACT OF THE THESIS OF

Michael L. Moses for the degree of Master of Science in Marine Resource Management presented on June 10, 2019.

Title: Professional Development Training in Ocean Acidification: A Case Study of Marine Resource Managers.

Abstract approved: ____

Burke R. Hales

Ocean acidification (OA) is the result of increasing concentrations of anthropogenic carbon dioxide (CO_2) emissions, leading to a suite of alterations to specific parameters of ocean chemistry, which can negatively impact many marine organisms and ecosystems. Understanding how to measure and monitor the chemistry of OA will require specialized education and training, which may be important for the marine resource managers called upon to devise management strategies in response to the impacts of OA. We can best serve these OA 'first responders' by making this information more accessible via appropriate educational products that enhance their learning and empower effective management decision-making.

For this study, we designed, developed, and piloted a professional training program on measuring and monitoring OA chemistry for marine resource managers in the Pacific Northwest. A companion survey was also developed in conjunction to assess outcomes in learning and professional behavior. Our participants demonstrated learning gains in key OA chemistry concepts, as well as changes in factors that indicated behavioral change. We present a training framework and its associated resources that science educators can use to deliver comparable training programs or build educational products to aid informal adult audiences in understanding and interpreting OA chemistry.

Professional Development Training in Ocean Acidification: A Case Study of Marine Resource Managers

by
Michael L. Moses

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented June 10, 2019
Commencement June, 2019

Master of Science thesis of Michael L. Moses presented on June 10, 2019.

APPROVED:

Major Professor, representing Marine Resource Management

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Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Michael L. Moses, Author

ACKNOWLEDGEMENTS

This thesis could not have been completed without the support and guidance of a community of mentors, peers, and family. I would like to express my sincerest appreciation to my committee: my advisor, Burke Hales, for the depths of his patience and expert guidance, Flaxen Conway, for her candor and unwavering kindness, Shawn Rowe, for his affirmations and enthusiasm, and Francis Chan, for his open door and many years of support and breakfasts. And thank you to my GCR, Lisa Gaines, for her earnest warmth and encouragement.

I am very grateful to the Marine Resource Managers who so willingly sacrificed their time and energy to participate in this study. The thoughtful contributions of these individuals were crucial to the success of this work. Thank you to Wendy and Eric Schmidt for their generous gift which supported the entirety of this project, and to the folks at OSU's Marine Studies Initiative for administering that gift and for their assistance throughout – Jane Lubchenco, Jack Barth, Kristen Milligan, and Virginia Neylon. I would also like to thank the folks at Sunburst Sensors for their assistance with the iSAMI, and Alan Barton and the rest of the hard-working crew at Whiskey Creek Shellfish Hatchery. A special thanks to the Dimmick family for the thoughtful and deeply meaningful gift of support.

A number of faculty, staff, and students in CEOAS and others beyond have provided me with guidance and assistance throughout this project and in the many years leading up to it, and are deserving of my thanks and recognition: Robert Allen, Lori Hartline, Will Fairchild and the other OEB graduate students, Joe Jennings, Andy Ross, Dale Hubbard, Angel White, George Waldbusser, Laurie Juranek, Jennifer Fehrenbacher, Brian Haley, Chris Russo, Mark Needham, the folks at Hatfield Marine Science Center - Cinamon Moffett in particular, the crews of the *R/V Oceanus* and *R/V Elakha*, my dear friends at PISCO and the rest of the people in the Lubchenco/Menge and Hacker labs, Ryan Mueller and his lab members, and a special thanks to Fiona Tomas Nash for her steadfast support and encouragement, without which truly none of this would have happened.

I would especially like to thank the members of the MRM graduate student community for their contributions to my learning and well-being. Their friendship, encouragement, attentiveness, camaraderie and cheer have provided me a touchstone for healthful and supportive working relationships that has affected me profoundly. I felt incredibly welcomed from the moment I walked in the door, thanks in large part to this extraordinary group that I would like to venerate: Tori Bohlen, Katie Darr, Bri Haugen, Dom Koné, Emily Mazur, Dani Miller, Jenn Moskel, Katy Nalven, and Anja Sjostrom.

Lastly, and most importantly, I would like to acknowledge the incredible sacrifice and support of my family. Committing to full-time graduate studies while caring for small children has been an absurdly difficult undertaking for all of us, but I cannot fathom my accomplishments without the love, encouragement, and immense sacrifices of my wife, Caroline Moses. She has shared in my victories and defeats throughout and been vital to helping me achieve my goals. And to my sons Wilderness Rain Moses and River Wy'east Moses: I hope someday you understand how much happiness, inspiration, and motivation you brought me throughout this process on a daily basis. Thank you.

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DEDICATION

This thesis is dedicated to all the other graduate student parents working to better their lives and the lives of their families. The graduate education experience is rarely designed to accommodate the unwavering demands of your daily life nor will you be likely to find an excess of sympathy and personal support along your journey, and yet you persevere. Your strength and determination are admirable in ways that I doubt others can ever fully understand.

"It is not the mountain we conquer, but ourselves."

- Sir Edmund Hillary

CHAPTER 1 INTRODUCTION

Ocean acidification (OA) is caused by rampant carbon dioxide (CO_2) emissions being absorbed into the world's oceans, leading to a decrease in global average surface ocean pH from 8.21 to 8.10 since the beginning of the industrial period (Doney et al., 2009; Feely et al., 2004). Often, OA is understood or communicated only in terms of this change in pH, but the reality involves a suite of changes to seawater chemistry which may not always be reflected by a given change in pH. These changes are likely to have detrimental impacts on a variety of organisms at different life stages, many of which may not be sensitive to the level of pH change associated with current OA (Orr et al., 2005; Waldbusser et al., 2015). Many of these species are ecologically and economically important, and provide an array of vital ecosystem services to human communities (Harley et al., 2006). Gaining a deeper understanding of the mechanisms behind these dynamic environmental changes, and how to measure and interpret them in context, is becoming increasingly important for marine resource managers to develop management strategies for the future.

A more thorough understanding of the dynamic nature of the impacts of OA will likely require an investment in understanding the chemistry that is driving it (Gattuso et al., 2013). This chemistry is described as the 'marine carbonate system' and involves a family of compounds that is related to the health, growth, and development of all marine organisms. Many marine resource managers may not have academic backgrounds centered on chemistry. Providing them with training that focuses on understanding the marine carbonate system and how it is measured can help empower them toward more salient and effective management decisions.

For this study, we designed, developed and tested a new hands-on professional development training for marine resource managers that focused on teaching the essentials of the marine carbonate system within the framework of OA, the different ways in which it can be measured, and what those values might mean for marine organisms. A secondary objective was to improve understanding of the knowledge gaps associated with this critical topic (Gattuso et al., 2013; Volmert et al., 2013) to help inform management and training strategies for the future. In the face of changing environmental conditions, managers frequently make increasingly shrewd decisions with regards to their time and efforts, relying on the science that is best available to them (Lester et al., 2010). The findings of this research could help connect managers and other adult learners with science that supports better understanding of OA and foster more informed decisions regarding the management of marine resources.

OCEAN ACIDIFICATION FIRST RESPONDERS

When the impacts of OA hit home, professionals who serve as marine resource managers will be among the first to notice and respond to its impacts. These OA 'first responders' may frequently observe these effects manifesting negatively in the organisms and environments they manage, but effective management responses will require specialized knowledge of seawater chemistry that is frequently reserved for ocean chemists and related subject matter specialists. Marine resource managers typically possess advanced degrees in scientific fields and are highly capable of interfacing with complex scientific information. They are largely employed by state and federal government agencies, municipal organizations, regional watershed councils and other non-governmental organizations (NGOs), industry, and local universities. Their job duties span a variety of disciplines and levels of responsibility, and may require knowledge and skills in natural science, data analysis and interpretation, technical problem-solving, communication, education, policy, and management. Examples of these professionals include living resource managers who may adjust harvest limits or manage habitats in response to changes in ocean chemistry, water quality managers who monitor local watersheds and discharges, coastal zone managers who make development and restoration decisions, or leaders in coastal resource industries such as oyster hatcheries or growers and commercial fishermen whose livelihoods may depend on local environmental quality (Boehm et al., 2015). People in these positions may be vital players in developing and implementing actionable strategies to address the OA problem. These roles may take the form of measuring, monitoring, managing, or mitigating local resources impacted by changes in the marine carbonate system. Many marine resource managers are already highly engaged with these issues but may find themselves needing additional information and skills to interpret the mechanisms and dynamics of the marine carbonate system and manage OA impacts. Dissemination of technical information to this audience to improve their fluency can take many forms, and many have expressed interest in access to hands-on professional development training programs. However, few if any such programs have been offered, particularly in the Pacific Northwest, leaving many in a position to either take no action, or potentially take improper or insufficient action towards handling OA issues. This thesis focuses on marine resource managers because of their interest and role in identifying the OA problem and their position interfacing with scientific practitioners, marine resource users, and the public. These OA first responders have a need for succinct, practical information about OA and potential to gain from professional development training.

Marine Carbonate Chemistry: The Key to Understanding OA?

The impacts of OA manifest themselves through a variety of interacting chemical mechanisms and can be difficult to predict. Making prescient management decisions, which can often rely on interpretation and communication of OA chemistry data, may be aided by an improved understanding of the chemical processes driving these impacts. Although many learners struggle with or may be fearful of chemistry (Herron, 1975; Sirhan, 2007) a strong educational design may help overcome some of that difficulty (Khourey-Bowers & Fenk, 2009). A more confident learner might be more likely to learn better, and be more likely to take action (Stajkovic, 2006), but the devil in the details of the chemistry must first be understood.

Inorganic carbon is present in seawater in a variety of chemical forms, referred to collectively as the marine carbonate system. Many of these parameters covary with one another as well as changes in physical and other chemical parameters such as temperature, pressure, and salinity. Under contemporary conditions, the ocean is a net sink for atmospheric CO_2, and nearly one-third of the fossil-derived CO_2 released by humans in recent decades has been absorbed by the global ocean via gas exchange between the atmosphere and ocean (Feely et al., 2004). This uptake results in a series of instantaneous changes to the carbonate system. CO_2 in seawater can be found as a dissolved gas ($CO_{2(aq)}$) which reacts with H_2O to form carbonic acid (H_2CO_3). Carbonic acid quickly releases (dissociates) one of its hydrogen (H^+) ions which combines with a carbonate (CO_3^{2-}) ion, resulting in the formation of two bicarbonate (HCO_3^-) ions. The measure of the abundance of H^+ in the system is known as pH, which is a useful indicator of acidic chemical species present in the system. The sum of $CO_{2(aq)}$ and H_2CO_3 concentrations is conceptually referred to as CO_2^*, reflecting the dominance of the $CO_{2(aq)}$ form over H_2CO_3, and the operational impossibility of analytically separating the two species. The partial pressure of CO_2 (pCO_2) is related to CO_2^* through gas solubility, which is the process that determines gas exchange at the air-sea interface. The sum of inorganic carbon species (CO_2^* + HCO_3^- + CO_3^{2-}) is known as 'total CO_2' (TCO_2) or dissolved inorganic carbon (DIC), which reflects changes to the carbonate system. The charge balance of the bicarbonate and carbonate ions, along with all other acid-base reactive ions, is known as 'total' or 'titration alkalinity' (TA) and represents the buffering capacity of the system. This buffering capability modulates the effects of OA and responds differentially from TCO_2 by many of the processes which impact the carbonate system. These processes may include gas exchange, photosynthesis, respiration, and dissolution and precipitation of calcium carbonate ($CaCO_3$), the primary building block of shells and other marine biomineral structures. The energetic favorability of the formation and dissolution of $CaCO_3$ minerals is proportional to its saturation state (Ω). Of the above components, TCO_2, pCO_2, pH, and TA are the directly measurable parameters of the marine carbonate system, while others can only be theoretically determined. Thermodynamic constraints allow the entirety of the system to be calculated by any combination of two of the four measurable parameters, providing temperature and salinity are known. A variety of methods and technologies exist to achieve this, and each is unique with regard to accuracy, precision, convenience, and cost.

Expert Knowledge to Practical Application

While some research has been conducted on learning and understanding of OA among K-12 audiences (Erickson, 2018b) and the public (Capstick et al., 2016), it often focuses primarily on either big-picture concepts or acid-base chemistry, without unpacking the dynamics of the marine carbonate system. A small handful of publications assess attitudes and understandings about OA among adult audiences such as undergraduates, university faculty, stakeholders, and OA "experts" (Danielson & Tanner, 2015; Gattuso et al., 2013; Mabardy et al., 2015; Volmert et al., 2013), but these also largely do not address the marine carbonate system and often package OA as a subtopic of anthropogenic climate change.

Subsequently, there remains a gap in the literature assessing understandings of the marine carbonate system, particularly among resource managers, who often conduct research, monitoring, and assessment work that may be impacted by OA. These professionals typically possess advanced knowledge of related concepts and the impacted environmental systems and organisms but may be less familiar with the details and dynamics of the chemistry requisite for performing and interpreting OA-related water quality measurements. Facilitating knowledge transfer from OA experts to managers will require careful consideration of learning needs, and previous research on what other adult audiences know about OA may provide insight into what to expect.

Volmert et al. (2013) assessed gaps in understanding of climate change and the role of the ocean by comparing surveys of OA experts with the general public. From this, they were able to develop four different "cultural models" by which people understand the mechanisms of climate change and its relationship to oceans. Their work built on previous surveys of the public a decade earlier, with which they were able to make comparisons, and sadly found that little had changed in public understanding during that time span.

Gattuso et al. (2013) conducted the first ever survey of experts on OA and found relatively high agreement of understanding among this audience on most general aspects of OA. High-level questions about timescales and biogeochemistry were asked, but no further details about carbonate chemistry. Interestingly, they found lower level of agreement regarding OA-related impacts on calcification, ecosystems and foodwebs, suggesting either a deeper level of nuance, or the presence of some misconceptions. Neither of the above publications specifically defined the level of expertise of their participants however, so it is unclear whether fair comparisons can be made between the two, or with other studies of this nature.

Danielson and Tanner (2015) surveyed undergraduate STEM majors from four different disciplines (biology, chemistry, environmental sciences, and geosciences) and compared their conceptions of OA with those of university faculty within the same disciplines. As one might expect, faculty had much more accurate awareness and understanding of OA than undergraduates as a whole, but environmental science students generally had higher awareness and a better grasp of the role of CO_2 than students in other disciplines.

Fauville et al. (2013) evaluated resources and efforts in OA education and identified key factors that may hamper success. Firstly, OA education frequently relies on or is driven by participation from subject matter specialists; however, most are not trained in education research or theories of learning. Secondly, they frequently lack experience in social science methods of evaluation, particularly regarding qualitative data. These findings highlight the importance of collaborations between educators, and natural and social scientists to create effective OA education programs.

While there is an apparent paucity of literature describing OA knowledge among marine resource managers, there is literature that indicates how scientific knowledge might be communicated to managers more effectively. Delivering an educational program reliant on expert knowledge must identify common ground to bridge the knowledge gap between experts and managers (Kocher et al., 2012; Ryan & Cerveny, 2011). Information transfer between these two groups is most effective when they are engaged in built relationships (Roux et al., 2006; Ryan & Cerveny, 2011). Understanding the types of information that is needed by managers, and the barriers to obtaining that information, will be key to successful communication and implementation (Cone & Winters, 2013; Roux et al., 2006). These outcomes can be facilitated through strong educational design that relies on effective strategies of knowledge transfer such as experiential learning and higher-order thinking processes about one's learning which are known to predict student performance (D. A. Kolb, 1984; Schneider & Artelt, 2010) and the likelihood toward behavioral change (Bandura, 1977; Briñol & DeMarree, 2012). Students who utilize these strategies beyond standard learning processes are more likely to attempt to achieve their goals through practical action (Pressley et al., 2010).

The Importance and Goals of Hands-On Experiential Learning

For this study, an emphasis on hands-on experiential learning was chosen for the design of the training program to maximize learner outcomes. Experiential learning is the process of learning by doing and has been shown to be an effective method of learning in higher education settings (A. Y. Kolb & Kolb, 2005), and in inquiry-based science teaching (Duran & Duran, 2004). The process of experiential learning follows a four-part cycle after an initial step of engaging the learner by means of a conceptual 'hook' (Bybee, 1990; D. A. Kolb, 1984, 2014).

The first phase in the experiential learning cycle begins with *exploration through concrete experience*, in which learners actively engage in physical tasks utilizing novel concepts, skills, and processes through exploration of their environment or materials and tools. The second phase of the cycle invites learners to verbalize or demonstrate their understanding through *reflective observation and explanation*. This is followed by the third phase in which learners are challenged to make sense of what they have learned through methods of interpretation by *elaboration of abstract conceptualization*. The final phase tests learners' understanding and skills through *evaluation by active experimentation* with demonstrations of planning and practice in a practical context. These phases of learning can be conceptually aligned with standards of authentic learning (higher-order thinking, substantive conversation, deep knowledge, and connectedness to the world; Knobloch (2003)) to facilitate a constructivist learning approach which promotes higher quality educational outcomes (Newmann, 1996).

Carefully planned professional development training programs are ideal settings to deliver hands-on experiential education for informal adult learners, and peer-reviewed literature offers guidance for how they can be created. Firstly, educators should utilize a theory-based approach in designing their programs. The theory of planned behavior posits that behaviors are predicted by intentions, which in-turn are predicted by attitudes, perceptions, and subjective norms (Ajzen, 1991). Professional development training programs that aim to influence changes in participants' behavioral intentions are more likely to do so if they employ strategies to address one or more of these concepts (Townsend et al., 2003). Other considerations for design include collaborating with outside subject matter specialists, sufficient devotion to organization and structure, a focus on authentic active learning, and engaging in follow-up and evaluation (Birman et al., 2000; Guskey & Yoon, 2009). For in-person science-based education, student understanding is constructed primarily through the processes of personal and social constructivism (Driver et al., 1994). This often occurs through meaning-making in dialogic processes, such as when learners engage socially through discussion and activities about shared problems and tasks, and is strengthened by support and guidance provided by instructional expertise.

However, an instructor's depth of knowledge of a given topic is a necessary but not sufficient condition to guarantee successful transfer of knowledge (Bybee, 1990). Professional development based on teaching and learning theory and practice, that relies on metacognitive strategies and other evaluative approaches, has increased potential to achieve desired outcomes (Bransford et al., 2000).

A Primer on Self-Efficacy

Hands-on training programs seek to not only cement knowledge and skills through authentic learning activities, but also to ultimately influence the behavioral intentions of the learners. Bridging the gap from behavioral intention to implementation requires a belief in one's ability to do so, a concept known as 'self-efficacy' (Bandura, 1977). Individuals who possess high self-efficacy are more likely to engage in behaviors that lead to achievement of goals, despite perceptions of barriers. Educational programs should see greater likelihood toward learner self-efficacy if their design incorporates elements of the five factors of self-efficacy (Bandura, 1977; Stajkovic, 2006):

Personal mastery experiences – achievements improve self-efficacy while repeated failures lower it, particularly early in the learning process.

Vicarious behavioral modeling experiences – witnessing the successful performance of peers improves expectations for success, particularly in learners with low initial confidence.

Social persuasion – people can be led by the suggestions of others to believe they are capable of achievement, particularly through positive reinforcement rather than negative reinforcement.

Perceptions of physiological response – by its nature, the learning process commonly induces stress and anxiety responses which act to impede learning, and can be compounded by delays in personal mastery, poor modeling experiences, and lack of positive reinforcement.

Perceptions of ability – how one perceives their ability to perform a task determines in part their core confidence, and this perception is strongly influenced by positive learning experiences.

The effectiveness of professional development programs designed to address these factors has been demonstrated, specifically for enhancing self-efficacy through constructivist learning in chemistry (Khourey-Bowers & Fenk, 2009), and hands-on use of technology (Watson, 2006). However, while this is effective in science learning, it is crucial to note the importance of assessing these outcomes. Changes in self-efficacy factors can only be appropriately captured if they are measured effectively using tested and well-designed assessment tools (Enochs & Riggs, 1990).

Study Purpose

The goal of this work was to teach marine resource managers about OA chemistry and how to measure it – this was accomplished through an educational intervention in the form of a professional development training program. This necessitated assessment and understanding of what marine resource managers already knew about OA chemistry – this was accomplished through review of scientific literature, interviews, and a survey. Second, it is important to understand how to design and test the training program to produce the desired outcomes. And third, these outcomes can be captured effectively through the development and use of a companion survey. Four research questions were at the heart of this study: 1) What do marine resource managers know about OA and marine carbonate chemistry? 2) How does a hands-on experiential learning program focused on OA and marine carbonate chemistry change this knowledge? 3) How might it influence their management behaviors and decision-making? 4) What are the best methods for testing and evaluating this kind of program?

To address the above research questions in the context of a professional development training case study, a mixed-methods approach was utilized that relied on a pre-post design to collect quantitative and qualitative data on participant perceptions and knowledge using interviews and a survey effort. Study participants were recruited via email and identified through a mix of professional connections, internet research, and snowball sampling, whereby future research participants are recruited by current research participants (Auerbach & Silverstein, 2003). Interviews were conducted in-person and over the phone one month before, and three months after, the training. A series of three questionnaires was delivered online via the Qualtrics application approximately two weeks before and after training, with a follow-up three months later. All three questionnaires measured participants' perceptions of OA knowledge, followed by an assessment of factual OA knowledge. The post-training questionnaire assessed their perceptions of each of the components of the training (lecture, lab, training satisfaction, etc.), and the follow-up questionnaire assessed participant perceptions of long-term changes to their behavior and learning needs and outcomes. Data were analyzed using Microsoft Excel, IBM SPSS 25, and Dedoose qualitative analysis software packages. Quantitative data from Likert-type scales were analyzed using a nonparametric Wilcoxon signed-rank test which analyzes changes in sample mean ranks of response ratings, while multiple choice survey question data were analyzed using McNemar's test which tests for differences between two related groups of responses. Qualitative data obtained from the interviews and open-ended survey questions were coded following standard procedures for axial and thematic coding whereby common themes expressed in participant responses are identified and indexed across responses, followed by writing analytic summaries of the themes within and among different topics (Maxwell, 2012).

THESIS OUTLINE

This thesis is written with two primary audiences in mind. Firstly, the science educator, teacher, university Extension agent, or professional development trainer looking for clues as to how to improve skills and understanding of OA and marine carbonate chemistry. Secondly, current and future marine resource managers who seek to understand better ways to solve an alarming global problem in their own local and regional contexts. The following chapters address the knowledge and training needs of marine resource managers and present results from a pilot training effort (CHAPTER 2). Results from this study are used to suggest a framework for training and evaluation (CHAPTER 3), and materials for this use are provided (APPENDICES). The conclusion (CHAPTER 4) makes suggestions for how the findings could be adapted to other informal adult learners and crafted and refined to improve outcomes to support marine resource managers.

References

Ajzen, I. (1991). The theory of planned behavior. *Organizational behavior and human decision processes, 50*(2), 179-211.

Auerbach, C., & Silverstein, L. B. (2003). *Qualitative data: An introduction to coding and analysis*: NYU press.

Bandura, A. (1977). Self-efficacy: toward a unifying theory of behavioral change. *Psychological review, 84*(2), 191.

Birman, B. F., Desimone, L., Porter, A. C., & Garet, M. S. (2000). Designing professional development that works. *Educational leadership, 57*(8), 28-33.

Boehm, A. B., Jacobson, M. Z., O'Donnell, M. J., Sutula, M., Wakefield, W. W., Weisberg, S. B., & Whiteman, E. (2015). Ocean acidification science needs for natural resource managers of the North American west coast. *Oceanography, 28*(2), 170-181.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn* (Vol. 11): Washington, DC: National academy press.

Briñol, P., & DeMarree, K. (2012). *Social metacognition*: Psychology Press.

Bybee, R. W. (1990). Science for life & living: An elementary school science program from biological sciences curriculum study. *The American Biology Teacher, 52*(2), 92-98.

Capstick, S. B., Pidgeon, N. F., Corner, A. J., Spence, E. M., & Pearson, P. N. (2016). Public understanding in Great Britain of ocean acidification. *Nature Climate Change, 6*(8), 763.

Cone, J., & Winters, K. (2013). Planning and evaluating science video programs using communication science. *Journal of Applied Communications, 97*(4), 9.

Danielson, K. I., & Tanner, K. D. (2015). Investigating undergraduate science students' conceptions and misconceptions of ocean acidification. *CBE—Life Sciences Education, 14*(3), ar29.

Doney, S. C., Balch, W. M., Fabry, V. J., & Feely, R. A. (2009). Ocean acidification: a critical emerging problem for the ocean sciences. *Oceanography, 22*(4), 16-25.

Driver, R., Asoko, H., Leach, J., Scott, P., & Mortimer, E. (1994). Constructing scientific knowledge in the classroom. *Educational researcher, 23*(7), 5-12.

Duran, L. B., & Duran, E. (2004). The 5E Instructional Model: A Learning Cycle Approach for Inquiry-Based Science Teaching. *Science Education Review, 3*(2), 49-58.

Enochs, L. G., & Riggs, I. M. (1990). Further development of an elementary science teaching efficacy belief instrument: A preservice elementary scale. *School science and mathematics, 90*(8), 694-706.

Erickson, B. D. (2018b). *Effects of Teaching Household Actions to Address Ocean Acidification on Student Knowledge and Attitudes.* (M.S. Thesis), Oregon State University, Corvallis, Oregon.

Fauville, G., Säljö, R., & Dupont, S. (2013). Impact of ocean acidification on marine ecosystems: educational challenges and innovations. *Marine Biology, 160*(8), 1863-1874.

Feely, R. A., Sabine, C. L., Lee, K., Berelson, W., Kleypas, J., Fabry, V. J., & Millero, F. J. (2004). Impact of anthropogenic CO2 on the CaCO3 system in the oceans. *Science, 305*(5682), 362-366.

Gattuso, J.-P., Mach, K. J., & Morgan, G. (2013). Ocean acidification and its impacts: an expert survey. *Climatic Change, 117*(4), 725-738.

Guskey, T. R., & Yoon, K. S. (2009). What works in professional development? *Phi delta kappan, 90*(7), 495-500.

Harley, C. D., Randall Hughes, A., Hultgren, K. M., Miner, B. G., Sorte, C. J., Thornber, C. S., . . . Williams, S. L. (2006). The impacts of climate change in coastal marine systems. *Ecology letters, 9*(2), 228-241.

Herron, J. D. (1975). Piaget for chemists. Explaining what" good" students cannot understand. *Journal of Chemical Education, 52*(3), 146.

Khourey-Bowers, C., & Fenk, C. (2009). Influence of constructivist professional development on chemistry content knowledge and scientific model development. *Journal of Science Teacher Education, 20*(5), 437-457.

Knobloch, N. A. (2003). Is experiential learning authentic? *Journal of Agricultural Education, 44*(4), 22-34.

Kocher, S. D., Toman, E., Trainor, S. F., Wright, V., Briggs, J. S., Goebel, C. P., . . . Steelman, T. A. (2012). How can we span the boundaries between wildland fire science and management in the United States? *Journal of Forestry, 110*(8), 421-428.

Kolb, A. Y., & Kolb, D. A. (2005). Learning styles and learning spaces: Enhancing experiential learning in higher education. *Academy of management learning & education, 4*(2), 193-212.

Kolb, D. A. (1984). Experience as the source of learning and development. *Upper Sadle River: Prentice Hall*.

Kolb, D. A. (2014). *Experiential learning: Experience as the source of learning and development*: FT press.

Lester, S. E., McLeod, K. L., Tallis, H., Ruckelshaus, M., Halpern, B. S., Levin, P. S., . . . Costello, C. (2010). Science in support of ecosystem-based management for the US West Coast and beyond. *Biological Conservation, 143*(3), 576-587.

Mabardy, R. A., Waldbusser, G. G., Conway, F., & Olsen, C. S. (2015). Perception and response of the US west coast shellfish industry to ocean acidification: The voice of the canaries in the coal mine. *Journal of Shellfish Research, 34*(2), 565-573.

Maxwell, J. A. (2012). *Qualitative research design: An interactive approach* (Vol. 41): Sage publications.

Newmann, F. M. (1996). *Authentic achievement: Restructuring schools for intellectual quality*: Jossey-Bass.

Orr, J. C., Fabry, V. J., Aumont, O., Bopp, L., Doney, S. C., Feely, R. A., . . . Joos, F. (2005). Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature, 437*(7059), 681.

Pressley, M., Borkowski, J. G., & Schneider, W. (2010). Cognitive strategies: Good strategy users coordinate metacognition and knowledge.

Roux, D. J., Rogers, K. H., Biggs, H., Ashton, P. J., & Sergeant, A. (2006). Bridging the science-management divide: Moving from unidirectional knowledge transfer to knowledge interfacing and sharing.

Ryan, C. M., & Cerveny, L. K. (2011). Wildland fire science for management: Federal fire manager information needs, sources, and uses. *Western Journal of Applied Forestry, 26*(3), 126-132.

Schneider, W., & Artelt, C. (2010). Metacognition and mathematics education. *ZDM, 42*(2), 149-161.

Sirhan, G. (2007). Learning difficulties in chemistry: An overview.

Stajkovic, A. D. (2006). Development of a core confidence-higher order construct. *Journal of Applied Psychology, 91*(6), 1208.

Townsend, M. S., Contento, I. R., Nitzke, S., McClelland, J. W., Keenan, D. P., & Brown, G. (2003). Using a theory-driven approach to design a professional development workshop. *Journal of nutrition education and behavior, 35*(6), 312-318.

Volmert, A., Baran, M., Kendall-Taylor, N., Lindland, E., Haydon, A., Arvizu, S., & Bunten, A. (2013). Just the Earth doing its own thing": Mapping the gaps between expert and public understandings of oceans and climate change. *Washington, DC: FrameWorks Institute*.

Waldbusser, G. G., Hales, B., Langdon, C. J., Haley, B. A., Schrader, P., Brunner, E. L., . . . Gimenez, I. (2015). Saturation-state sensitivity of marine bivalve larvae to ocean acidification. *Nature Climate Change, 5*(3), 273.

Watson, G. R. (2006). Technology professional development: Long-term effects on teacher self-efficacy.

CHAPTER 2 FIRST MANUSCRIPT [JRST]

OCEAN ACIDIFICATION KNOWLEDGE AND TRAINING NEEDS FOR MARINE RESOURCE MANAGERS: OUTCOMES FROM A PROFESSIONAL DEVELOPMENT PILOT PROGRAM

ABSTRACT

Ocean acidification (OA) issues are a growing concern for natural resource managers working in marine ecosystems, and the dynamics of OA and its impacts on marine resources are still being understood. Measuring and monitoring these changes in ocean chemistry can be challenging, requiring specialized education and training, and the managers called upon to perform these tasks are increasingly seeking the requisite tools and information to conduct this work. In this mixed-methods case study, we explore a group of professionals' knowledge about OA and the marine carbonate system, and examine the outcomes of participating in a hands-on, experiential learning-based professional development training program on OA measuring and monitoring. Our research participants demonstrated persistent and significant learning gains on key knowledge indicators. These gains were accompanied by increases in confidence, and many expressed that hands-on laboratory learning was instrumental in this result. Additionally, post-training outcomes in knowledge application and behavioral implementation can help identify remaining learning needs, and how the science community can provide assistance to resource managers. These results can be used to inform future informal education, training, and evaluation efforts to facilitate enhancements in participant self-efficacy outcomes.

INTRODUCTION

Ocean acidification (OA) is the result of unprecedented input of anthropogenic carbon dioxide (CO_2) into the world's oceans, which alters carbonate chemistry, including a decrease in pH (Doney et al., 2009; Feely et al., 2004). Some of these changes to the marine carbonate system make it increasingly difficult for many calcifying organisms to build and maintain shells and other biomineral structures (Barton et al., 2012; Waldbusser et al., 2015), among other impacts. Detrimental effects are anticipated to be particularly strong for many ecologically, economically, and socially important marine organisms such as oysters, crabs, and eelgrass, which play key roles in structuring and organizing ecological communities (Arnold et al., 2012; Miller et al., 2016; Waldbusser et al., 2015) and provide vital ecosystem services to human societies (Harley et al., 2006). Coastal regions that undergo seasonal upwelling (such as the Pacific coast of North America) experience frequent dynamic changes in marine carbonate chemistry (MCC) values and may be particularly vulnerable to OA as a result (Barton et al., 2012; Feely et al., 2016; Hales et al., 2005). Gaining a deeper understanding of the mechanisms behind these dynamic environmental changes is becoming increasingly important for scientists and marine resource managers to feel prepared to respond to future changes (Boehm et al., 2015).

Marine resource managers can be viewed as OA 'first responders' as they frequently make decisions involving the measuring, monitoring, managing, or mitigating of OA impacts on marine resources, and will have increasing need to incorporate considerations for changing acidification regimes. In order to make effective and informed management decisions in response to OA, marine resource managers need a solid understanding of the chemical mechanisms and environmental dynamics driving OA. Boehm et al. (2015) outlined decision-making models and their associated informational needs for managers and management stakeholders to be able to incorporate considerations for OA into their management decision-making. These models classify the types of resources being managed, the necessary variables and parameters for coupled physical-biochemical models, and what combination of data and information is needed. Marine resource managers who utilize these decision-making frameworks must already possess an operational understanding of MCC. However, while general OA knowledge has been described for the public (Capstick et al., 2016) and OA experts (Gattuso et al., 2013), it is unclear what marine resource managers as a group already know about MCC, what the best way is to teach it, and whether doing so results in any meaningful change in management outcomes.

A dilemma exists then in not only identifying OA learning needs and how to change knowledge baselines, but also understanding the influence of this learning on salient and effective resource management decision-making. Identifying managers' information needs and barriers to implementation, and incorporating them into a strong evaluation of educational delivery, are important influences on the likelihood of managers to act (Cone & Winters, 2013; Ryan & Cerveny, 2011). The educational framework and its methods of evaluation should include assessments of learner knowledge, perceptions, and confidence, to facilitate higher-order thinking processes (metacognition) which can influence confidence and ultimately behavioral change (Briñol & DeMarree, 2012; Molenberghs et al., 2016).

The ability of an individual to make decisions or change behavior relies in part on one's confidence and perception of barriers (Enochs & Riggs, 1990), and this confidence can be improved through experiential learning, which is an effective method for improving retention through a process of learning by doing through projects, problem-solving, and real-life contexts, (Knobloch, 2003; D. A. Kolb, 1984). Professional development training programs are common methods of informal education for adult professionals and incorporating active learning has been demonstrated to improve successful learning outcomes (Birman et al., 2000). A well-designed and tested professional development program incorporating these elements in the curriculum and evaluation tool would be an appropriate and effective educational framework to deliver an OA-centered chemistry curriculum and evaluate outcomes in learning and behavioral change.

This study sets out to document the current level of knowledge and understanding of OA and MCC among marine resource managers to help identify learning and training needs. To do this, we piloted a hands-on, experiential learning professional development training program to improve working understanding of MCC dynamics and measurement as it relates to OA. Potential influences on management behaviors and decision-making were also identified through outcomes in confidence and perceptions of barriers and continuing needs. Results presented here point toward refinements in future training efforts and evaluation that can be used to target key questions about the importance of learning MCC to better understand OA, and its impact on how marine resource managers perceive their ability to manage their resources.

METHODS

STUDY PARTICIPANTS

Marine resource managers in Oregon and Washington were identified through professional connections and internet searches and contacted via email soliciting their participation in this research including a professional development training workshop. Participants were selected based on proximity to OA impacts in their professional positions. The study design and implementation followed standard social science protocols (Auerbach & Silverstein, 2003; Dillman, 1978), was awarded university human subjects Institutional Review Board approval, and all study participants provided their informed consent. Respondents were randomly assigned identification numbers to anonymize their identities for analysis.

Participants first participated in a pre-training questionnaire and were then parsed based on compatible scheduling for the workshop, and two follow-up questionnaires later administered to workshop attendees. Semi-structured interviews (Auerbach & Silverstein, 2003) of willing participants were conducted approximately one month beforehand to identify learning needs and desires and inform workshop and questionnaire design. In all, a total of 29 people participated in this research, and of those, 19 attended the training.

Approximately 72% of all respondents were employed by state government agencies, with the remainder shared between universities (14%), NGOs (7%), or other entities (7%). Although approximately 76% of participants reported possessing a graduate degree, 52% reported having no educational experience related to OA, with another 31% reporting 'A little' (Table 2.1). Additionally, 90% reported having some amount of professional experience related to OA, with none of the participants reporting their educational background as "a lot" or "entirely" focused on OA or MCC.

Table 2.1 Baseline OA and MCC experience
Percentages of participants with educational or professional experience with OA or MCC (*n* = 29)

	Educational Experience	Professional Experience
None	52	10
A little	31	34
Some	17	41
A lot	0	14
Entirely	0	0

Professional Development Training

The training program focused on understanding and measuring the chemistry of OA and was designed following the 5E Instructional Model (Bybee, 1990; Duran & Duran, 2004). It consisted of two optional pre-training webinar lectures, and a two-day in-person workshop that featured a blend of academic-style lectures and hands-on experiential laboratory learning. It was delivered by subject matter specialists from Oregon State University in August of 2018 at Hatfield Marine Science Center (HMSC) in Newport, Oregon.

Lectures

In the two weeks preceding the workshop, two optional webinar-based lectures were delivered live using the WebEx application to provide broad contextual information about OA. They focused on the biological impacts of OA and the global carbon cycle, respectively, but did not address chemistry or measurement. During the workshop, three primary lectures were delivered that covered the dynamics of marine carbonate chemistry, and the principles and methods of measuring these variables, respectively.

Laboratory

The laboratory portion of the workshop consisted of four sessions focused on practical application and hands-on learning of MCC principles and measurement. The initial laboratory session focused on improving understanding of the dynamics of the carbonate system through a series of tasks using the CO2SYS carbonate system calculator (Pierrot et al., 2006), which allowed the participants to synthetically assess the interconnections between the variables of the carbonate system. Three subsequent wet-lab sessions focused on methods for measuring and constraining carbonate system variables, with increasing complexity. In the first wet-lab session they learned proper calibration of off-the-shelf pH meters and measurement of seawater pH, using HMSC flow-through seawater. Carbonate system measurements from a Burke-o-Lator pCO_2/TCO_2 analyzer and a Sunburst Sensors iSAMI pH sensor were provided for comparison. In the second lab session, participants learned a simple method for estimating seawater total alkalinity (TA) using a method adapted from Liu et al. (2015). They applied these methods first on seawater samples collected from the HMSC flow-through system, then on discrete field samples the participants had independently collected prior to the workshop. Simultaneously, instructors analyzed carbonate system variables on replicate discrete samples using the Burke-o-Lator. Using these measurements, participants were able to constrain the entire carbonate system, and compare the accuracy and uncertainties of each method. In the final wet-lab session, participants were given free choice to repeat and refine any combination of measurement methods on subsequent replicate samples, with the option for guided instruction using the Burke-o-Lator and iSAMI instruments.

RESEARCH PROCEDURES

Survey Design

A series of three questionnaires was delivered to participants to collect quantitative and qualitative data regarding their perceptions and knowledge of OA, workshop feedback, and long-term learning and behavioral outcomes. They were composed of a mix of Likert-type, semantic differential, multiple choice, and open-ended questions. Questionnaires were created following guidelines from Dillman (1978) and Vaske (2008). Six declarative statements taken from Gattuso et al. (2013) were used to assess participants' broad understanding of OA in a global context but were ultimately excluded from this analysis (see APPENDIX H: BROAD OA KNOWLEDGE QUESTIONS RESULTS: COMPARISON TO GATTUSO ET AL. (2013)). The initial pre-training questionnaire (t0) was administered approximately two weeks before the in-person workshop and collected prior to delivery of the first webinar broadcast. Post-training and follow-up questionnaires were administered at approximately two weeks (t1) and three months (t2) following the workshop. Due to the geographic distribution of participants, questionnaires were constructed and delivered on the internet using the Qualtrics application.

All three questionnaires featured identical sections surveying participants regarding perceptions of their own understanding of OA, followed by a factual knowledge assessment. The pre-training questionnaire (t0) also collected demographic information regarding their level of education and professional experience, as well as their employment classification. The post-training questionnaire (t1) included sections evaluating the different workshop components, while the follow-up questionnaire (t2) included sections assessing long-term outcomes in learning, self-efficacy, and behavior.

Perceptions of OA Understanding. Participants provided an agreement rating for a set of eight statements assessing perceptions of their own level of understanding of OA and MCC, as well as that of their colleagues, and the relevance of that knowledge to what they do professionally. These statements utilized a 1-100 Likert-type slider on a symmetric agreement scale, with seven ordered response levels from 1 = "Strongly disagree" to 100 = "Strongly agree". Questions were paired such that the first in each pair referenced ocean acidification but was followed by a similarly phrased companion question that asked more specifically about MCC or carbonate system variables, to separately evaluate the carbonate chemistry aspects of the concept. Each section concluded with an open-ended question soliciting respondents for general feedback or comments related to the statements.

Factual Knowledge Assessment. Respondents answered nine multiple choice questions testing their knowledge on key OA and MCC concepts and details covered by the webinars and in-person training. Each question provided one correct option, three incorrect options, and an "I don't know" option.

Program Evaluation. The first post-training questionnaire featured eight sets of questions used to gather participant feedback on each component of the training, as well as on the entire workshop generally. This feedback was collected using the same agree-disagree Likert-type scale as before, as well as multiple choice and open-ended questions where appropriate. Respondents evaluated webinars, lectures, and laboratory sessions using a repeated set of approximately twelve declarative statements to gather their perceptions on how relevant they found the information, how interested they were in it, and how well it was delivered. An additional set of twelve statements was asked which focused more specifically on assessing perceptions of self-efficacy factors as a result of the tasks performed in the laboratory. Participants also evaluated their overall level of satisfaction with the training, as well as other features of the training such as the comfort with facilities and the quality of instruction. Open-ended questions in each section focused on prompting respondents to explain how they believe the training is relevant to their job, and the relationships between their level of understanding and their educational and professional experiences.

Long-term Outcomes. The follow-up questionnaire featured four new sets of statements evaluating participants' needs and behavioral changes regarding learning, the frequency and manner with which they talk about OA, and their decision-making on the job either in general, or specifically related to their use of oceanographic instrumentation and data. Open-ended questions were largely metacognitive in nature, focusing on identifying self-efficacy drivers and barriers.

Interviews

Select workshop participants were interviewed based on availability several weeks prior to the training, and after three months post-training. The two sets of interviews had differing goals and were not intended to be used for pre-post comparison. Pre-training interviews followed a standardized open-ended format (Auerbach & Silverstein, 2003) featuring five questions and were conducted by phone or in-person. The goal of the pre-training interviews was to gain a better understanding of what participants do for their jobs and how it related to OA, and to understand better their incoming level of knowledge to help articulate educational needs and curricular design better. Post-training interviews featured fifteen questions that followed a standardized open-ended format and were delivered in-person. These interviews were used to understand more deeply how the workshop impacted participant learning and understanding of OA and MCC, how that may have influenced their behavior or sense of confidence toward action on the OA problem, and how they felt the structure of the workshop contributed to these outcomes. A total of 14 interviews were conducted among 11 participants (pre: $n = 9$, post: $n = 5$) and were ceased when responses had reached theoretical saturation, indicating concepts had been thoroughly addressed (Miles et al., 1994). Qualitative data gathered in these interviews is intended to provide a more contextual understanding of participant experiences with the workshop, as well as elaboration of their long-term needs and outcomes as a result of their participation.

Data Analysis

Quantitative questionnaire response data were analyzed using MS Excel and IBM SPSS 25 software. Changes in questionnaire responses over time (t0, t1, t2) were analyzed in SPSS using Wilcoxon signed-rank test, which analyzes changes in sample mean ranks of response ratings, and McNemar's test, which tests for differences between two related groups of responses. Qualitative data from interview and open-ended survey questions were recorded and coded using MS Excel and Dedoose qualitative analysis software. Coding followed axial-coding procedures used for thematic coding, whereby common themes expressed in qualitative data are identified and indexed across responses (Maxwell, 2012). The initial phase of coding identified 'parent' codes which group responses together according to generalized themes or topics that are either concordant with the themes of the questions asked, or naturally emerge from participant responses. The subsequent iterative phases of coding identified 'child' codes which are repeating sub-themes or sub-topics that are clustered within the broader themes. These themes are then further organized and identified through a process of writing analytic memos to summarize themes within and among topics (Auerbach & Silverstein, 2003). A summary of select code applications are presented in Table 2.2. Efforts to ensure validity of qualitative data were made by conducting a validity threat checklist exercise as outlined in Maxwell (2012), whereby the researcher identifies evidence that could plausibly challenge methodology or the conclusions made, and outlines strategies to address it (see: APPENDIX J: RESEARCH DESIGN VALIDITY MATRIX).

Table 2.2 Qualitative code applications

Select code applications which received mentions, or whose parent codes received mentions, by greater than two-thirds of respondents in interview and open-ended survey question responses (*n* = 19).

Parent Code / Child Code	Explanation of Mentions	Number of Mentions	Proportion of Respondents
Job	References to ways in which attending the workshop has influenced their working life with regards to scope, needs, intentions, ability, relevance, perceptions, interactions, or goals.	137	1.00
Job / Role	Perceptions of their professional role with respect to addressing the impacts of OA.	42	.79
Job / Role / Monitoring	Perceptions that the primary role in which they view themselves capable of addressing the impacts of OA is or will be fulfilled through monitoring efforts.	30	.68
Job / Collaboration	Collaboration with OA experts, science educators, and/or resource management peers valued as need, desire, or goal for job success with respect to addressing OA.	31	.68
Job / Better/effective	Respondents reporting (prompted and unprompted) that workshop attendance positively contributed to their ability to do their job or do it more effectively.	25	.53
Communication	Reference to the impact of the workshop on outcomes related to their ability or engagement in communicating about OA/MCC manifested as changes in thought processes, talking, public interactions or engagement, or other changes to work-related communication processes.	53	.95

Communication / Talk	Specific references to changes in ability, frequency, or the way they talk about OA/MCC as a direct result of attending the workshop.	24	.84
Barriers	External barriers to their ability utilize or apply knowledge or skills obtained from the workshop.	41	.84
Learning / Science	Post-training perceptions of importance of scientific information and/or expertise in addressing OA.	41	.79
Learning / Needs	Understanding of or concerns about remaining post-training learning or knowledge needs.	27	.58
Workshop / Lab	Importance or relative contributions of laboratory portions of workshop to their learning and/or other long-term outcomes.	40	.79
Workshop / Hands-on	Importance or relative contribution of hands-on components of the workshop experience to their learning and/or other long-term outcomes.	64	.74
Workshop / Hands-on Accuracy	Impressions or concerns that measurement accuracy, precision, and/or error are important considerations when obtaining carbonate system measurements.	26	.63
Workshop / Lecture	Importance or relative contributions of lecture portions of workshop to their learning and/or other long-term outcomes.	38	.63

RESULTS

BASELINE OA PERCEPTIONS AND KNOWLEDGE

Perceptions

Overall, survey respondents tended to agree with statements of perceptions about their own understanding of OA and MCC, that of their colleagues and co-workers, and the relevance to their jobs (Table 2.3). Statements 4 ($\bar{x}$ = 46) and 6 ($\bar{x}$ = 48) were the only statements with overall mean ratings $\bar{x}$ < 50, indicating slight disagreement collectively. Despite a mean agreement response rating of $\bar{x}$ = 77 for statement 1 ("I understand ocean acidification"), respondents provided a lower rating ($\bar{x}$ = 61) when asked to rate a similar statement about their colleagues and coworkers for statement 5. Similarly, when asked to provide an agreement rating for statement 2 ("I understand marine carbonate chemistry"), respondents provided a higher rating ($\bar{x}$ = 58) than when similarly asked about their colleagues and coworkers in statement 6 ($\bar{x}$ = 48). Overall however, respondents provided relatively strong agreement ratings for statements about the relevance of OA to their jobs ($\bar{x}$ = 90), and the effectiveness of learning more about marine carbonate chemistry ($\bar{x}$ = 77).

Table 2.3 Baseline OA and MCC perceptions

OA and MCC self-knowledge perceptions among surveyed marine resource managers (n = 28)

	Mean ratings of statement agreement and standard deviations[1]			
	$\bar{x}$	S.D.	Min.	Max.
1. I understand ocean acidification	77	15	33	100
2. I understand marine carbonate chemistry	58	23	16	95
3. I understand how to measure ocean acidification	58	25	10	96
4. I understand how to measure carbonate system variables	46	27	0	95
5. My colleagues/co-workers understand ocean acidification	61	25	0	100
6. My colleagues/co-workers understand marine carbonate chemistry	48	25	0	100
7. Ocean acidification issues are relevant to my job	90	14	46	100
8. Learning more about marine carbonate chemistry will help me be more effective at my job	77	27	2	100
Overall (mean)	64	23	13	98

[1] Mean response ratings on 100-point scale from 1 "strongly disagree" to 100 "strongly agree."

Factual Knowledge

Respondents were tested using nine multiple-choice factual knowledge questions about OA and MCC (Table 2.4). Each question offered only a single correct answer out of four possible choices, plus an option to select "I don't know". Responses were recoded where correct answers = '1', and incorrect answers or 'I don't know' = '0', and the proportion of correct responses for each question calculated. The questions were intended to progress from broad concepts to more specific details of OA chemistry, but this pattern did not bear out in baseline results among all respondents prior to training. Respondent knowledge was highest for questions 15, 17, and 18, while knowledge was lowest for question 16, which was answered correctly by only a single respondent over the entire survey.

Table 2.4 Baseline factual knowledge

OA and MCC factual knowledge results among surveyed marine resource managers (*n* = 28)

	Proportion who answered correctly and standard deviation[1]	
	Overall	S.D.
15. Where is the largest active reservoir of carbon on the planet found? (The ocean)	.70	.45
16. What are the three carbon pumps of the ocean? (Carbonate, soft tissue, solubility)	.04	.19
17. Which of the following is most likely to benefit under ocean acidification conditions? (Seagrasses)	.85	.38
18. A decrease in pH is a measure of what? (Increase in hydrogen ion [H+] concentration)	.89	.31
19. The dissolved inorganic carbon (DIC) pool consists of which combination of the following? (Carbonic acid, carbon dioxide, carbonate ion, bicarbonate ion)	.52	.50
20. How many carbonate chemistry variables do we need to know in order to constrain the entire carbonate system? (Two)	.19	.38
21. What ancillary variables must be measured alongside carbonate system variables, to characterize the entire carbonate system? (Temperature and salinity)	.44	.49
22. Which of these carbonate system variables is not directly measurable? (Omega)	.56	.50
23. Which of the following does not impact alkalinity? (CO2 gas exchange)	.11	.31
Overall	.48	.39

[1] Recoded multiple-choice questions where 1 = correct, 0 = incorrect. Individual question proportions represent share of respondents who answered each question correctly.

Change in OA Perceptions and Knowledge

Perceptions

Among those marine resource managers who participated in the hands-on training program, statistically significant changes were observed for five of the eight initial perceptions statements using a Wilcoxon signed-rank test which analyzes changes in sample mean ranks of response ratings (Table 2.5). Pairwise comparisons of individual time intervals revealed significant increases from pre-training (t0) to post-training (t1) for statements 2 (p = .011), 3 (p = .002), and 4 (p = .001). These significant increases were not negated by the slight decreases observed over the t1-t2 time interval for these same statements. The largest increases in mean response ratings of all eight statements were also observed for these three statements over this same time interval, with the largest increase observed for statement 4 (Δ = 36), which also had the lowest incoming response mean ($\bar{x}$ = 40). Decreases in response means from t0-t1 were observed for statements 5 – 8 but was only statistically significant for statement 8 (p = .023). Of all statements, only statement 2 showed a decrease in mean agreement response rating from t1-t2 (Δ = -4), but it was not significant (p = .470). A statistically significant decrease in agreement response means from t1-t2 was only observed for statement 5 (p = .046). Boxplots in Figure 2.1 show changes over time among all eight statements. The significant shifts from t0-t3 for statement 2 and from t1-t2 for statement 5 are not readily apparent as differences in means but are significant according to shifts in distribution of responses when measured as differences in mean ranks as assigned by the Wilcoxon signed-rank test.

Table 2.5 Change in OA knowledge perceptions
Comparisons of pre-training (t0), post-training (t1), and follow-up (t2) results using Wilcoxon signed-rank test (n = 15)

	Average rating of statement agreement and (standard deviation)[1]			*p*-value		
	t0	t1	t2	t0-t1	t1-t2	t0-t2
1. I understand ocean acidification	75 (17)	77 (17)	81 (14)	.269	.409	.231
2. I understand marine carbonate chemistry	53 (28)	71 (18)	67 (23)	.011	.470	.035
3. I understand how to measure ocean acidification	53 (29)	79 (12)	78 (12)	.002	.950	.005
4. I understand how to measure carbonate system variables	40 (31)	76 (13)	78 (13)	.001	.894	.001
5. My colleagues/co-workers understand ocean acidification	63 (27)	59 (22)	65 (20)	.507	.046	.777
6. My colleagues/co-workers understand marine carbonate chemistry	48 (28)	46 (22)	51 (25)	.850	.257	.477
7. Ocean acidification issues are relevant to my job	90 (17)	86 (23)	86 (15)	.182	.358	.168
8. Learning more about marine carbonate chemistry will help me be more effective at my job	83 (25)	76 (21)	77 (19)	.023	.844	.168

[1] Mean response ratings on 100-point scale from 1 “strongly disagree” to 100 “strongly agree.”

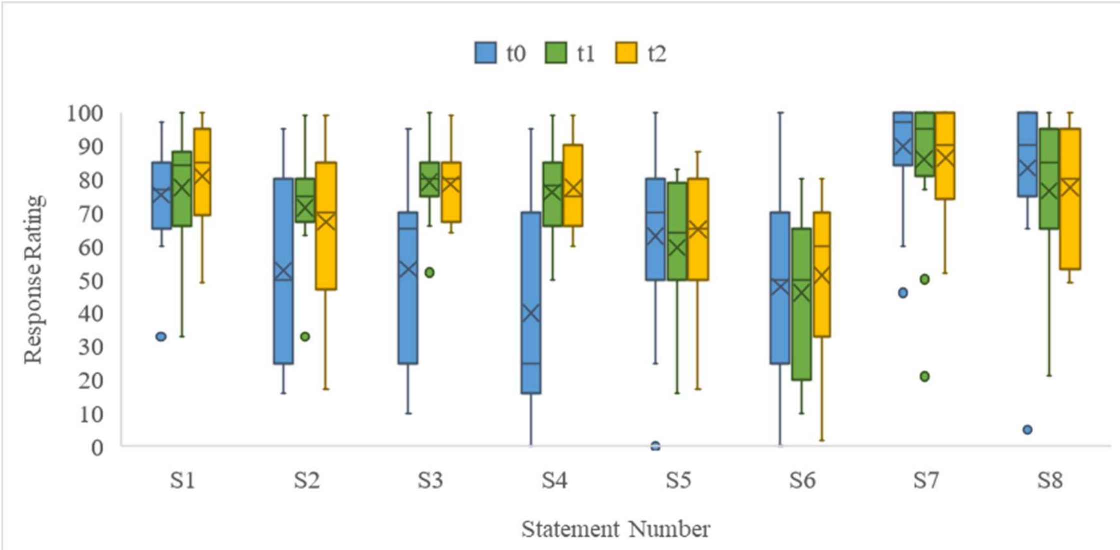

Figure 2.1 Change in OA knowledge perceptions.
Box-and-whisker plot representing change in OA knowledge perceptions over time. Blue boxes represent pre-training (t0) responses among participants. Green boxes represent post-training (t1) responses. Yellow boxes represent follow-up (t2) responses, for *n* = 15 respondents following listwise deletion and exclusion of outliers.

Factual Knowledge

Post-training results of the factual knowledge assessment revealed increases in the proportion of questions answered correctly for six of the nine questions, and these increases were not wholly negated over time in the follow-up results, despite some slight decreases in means (Table 2.6, Figure 2.2). Results of McNemar's test analyzing pairwise comparisons of grouped responses revealed significant increases from t0-t1 for questions 20 ($p < .001$), 21 ($p = .001$), and 22 ($p = .031$). These increases remained significant from t0-t2 for questions 20 ($p = .002$) and 21 ($p = .003$), but not 22 ($p = .375$). Pre-training knowledge was highest for questions 15, 17, and 18, and remained relatively high throughout. Question 18 had the highest pre-training mean ($\bar{x} = .88$) and was the only question to exhibit a decrease in means from t0-t1 ($\bar{x} = .81$) but exceeded both pre and post-training means in the follow-up ($\bar{x} = .94$). Question 17 had the second-highest pre-training mean ($\bar{x} = .81$), which changed relatively little over the course of the survey. Pre-training knowledge was equally low for questions 20 and 23, but question 23 did not exhibit nearly as large of a post-training increase ($p = .219$). Knowledge was lowest overall for question 16, with only two respondents answering it correctly. Changes in means were not significant for any question from t1-t2.

Table 2.6 Change in OA factual knowledge
Comparisons of pre-training (t0), post-training (t1), and follow-up (t2) results using McNemar's test (n = 16)

	Proportion answered correctly and (standard deviation)[2]			*p*-value		
	t0	t1	t2	t0-t1	t1-t2	t0-t2
15. Where is the largest active reservoir of carbon on the planet found? (The ocean)	.69 (.48)	.88 (.34)	.75 (.45)	.250	.500	1.000
16. What are the three carbon pumps of the ocean? (Carbonate, soft tissue, solubility)	.00 (.00)	.06 (.25)	.06 (.25)	1.000	1.000	1.000
17. Which of the following is most likely to benefit under ocean acidification conditions? (Seagrasses)	.81 (.40)	.81 (.40)	.88 (.34)	1.000	1.000	1.000
18. A decrease in pH is a measure of what? (Increase in hydrogen ion [H^+] concentration)	.88 (.34)	.81 (.40)	.94 (.25)	1.000	.500	1.000
19. The dissolved inorganic carbon (DIC) pool consists of which combination of the following? (Carbonic acid, carbon dioxide, carbonate ion, bicarbonate ion)	.50 (.52)	.50 (.52)	.56 (.51)	1.000	1.000	1.000
20. How many carbonate chemistry variables do we need to know in order to constrain the entire carbonate system? (Two)	.06 (.25)	.94 (.25)	.69 (.48)	<.001	.125	.002
21. What ancillary variables must be measured alongside carbonate system variables, to characterize the entire carbonate system? (Temperature and salinity)	.19 (.40)	.94 (.25)	.94 (.25)	.001	1.000	.003
22. Which of these carbonate system variables is not directly measurable? (Omega)	.44 (.51)	.81 (.40)	.63 (.50)	.031	.250	.375
23. Which of the following does not impact alkalinity? (CO_2 gas exchange)	.06 (.25)	.31 (.48)	.25 (.45)	.219	1.000	.375

[1] Recoded multiple-choice questions where 1 = correct, 0 = incorrect. Individual question proportions represent share of respondents who answered each question correctly.

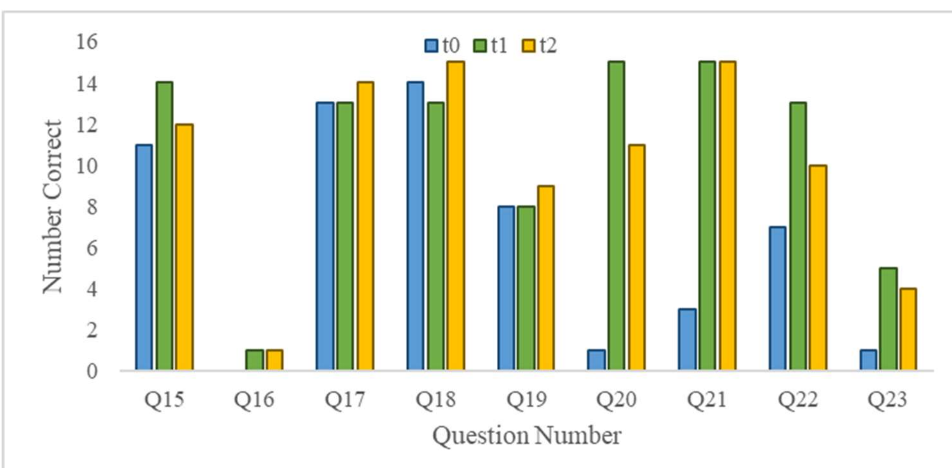

Figure 2.2 Changes in OA factual knowledge.
Bar chart of cumulative correct responses to multiple choice OA factual knowledge questions among training participants (n = 16) pre-training (blue), post-training (green), and follow-up (yellow).

OTHER OUTCOMES OF PROFESSIONAL DEVELOPMENT TRAINING

Learning about Marine Carbonate Chemistry

Addressing OA issues is likely to require deeper understanding of carbonate chemistry, and educational programs designed to disseminate this knowledge and careful consideration should be given as to how to present that information in a digestible manner. Not all marine resource managers will require expert-level understanding of MCC, and conceptual change in learners may be driven in-part by how this content is contextualized and reinforced. We asked our participants to rate how strongly each component of the workshop contributed to their existing knowledge of MCC (Figure 2.3), to aid in the refinement and targeted delivery of the training curriculum. Only 10 of the in-person workshop participants attended the two pre-training webinars, while responses from 15 participants are represented for the other workshop components. Lecture 1 (Carbonate Chemistry), demonstrated the most consistent agreement among respondents (IQR = 14), with a mean agreement scale response rating of $\bar{x}$ = 81. Similarly, strong agreement was demonstrated in responses regarding the lab sessions generally ($\bar{x}$ = 82, IQR = 18), and specifically for the hands-on tasks performed during the lab sessions ($\bar{x}$ = 82, IQR = 16). Several participants noted that the webinar lectures provided broad context for their

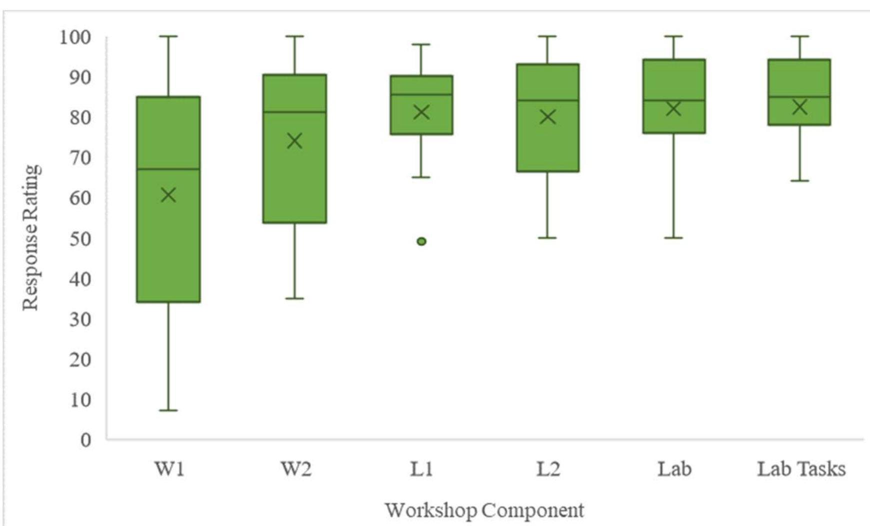

Figure 2.3 Lecture and lab contributions to MCC understanding.
Box-and-whisker plot of participant agreement responses to the statement, "…contributed to my existing knowledge of marine carbonate chemistry", for each webinar (W1, W2), lecture (L1, L2), or lab component. W1 & W2 *n* = 10, for all others *n* = 15.

understanding of OA and MCC, while the in-person lectures provided deeper conceptual understanding, particularly with regard to measurement of carbonate chemistry parameters.

When asked how the lab sessions and measurement tasks contributed to their understanding of MCC, there was strong agreement that performing the measurement tasks in a practical, hands-on way was essential to helping solidify their understanding, and that having an experienced, knowledgeable person perform these measurements is vital to the quality of the results. When asked "In what ways might this information help you with your job?", respondents noted not only that it will help them understand and interpret measurement data, but also improve their ability to explain OA issues to others.

> *"It turns out that I had even less understanding of carbonate chemistry than I thought. Having a better understanding helps me look to the future for managing our susceptible resources. It also helps me explain the issue of OA better to different audiences."*

The themes summarized in the quote above were echoed by other participants as well and point to the importance of learning the carbonate chemistry piece, and also suggest the relevance for empowering learner confidence and changes in behavior which may ultimately impact management outcomes.

Post-training Learning Needs

Perceptions of remaining learning needs were assessed in the follow-up questionnaire to better understand long-term post-training impact on participant learning and confidence (Figure 2.4). Participants demonstrated good metacognitive awareness when providing an agreement scale response to whether they had "encountered or identified gaps in [their] knowledge that [they] would not have previously recognized" (S25: $\bar{x}$ = 85, IQR = 12). While workshop participants generally reported high levels of satisfaction with the training, they also demonstrated broad agreement that they still want (S28: $\bar{x}$ = 83) and feel they still need (S29: $\bar{x}$ = 88), additional training. Respondents showed strong agreement in knowing where to find additional information about OA and MCC if they needed it (S31: $\bar{x}$ = 81), and that they would be able to "figure out" information that was difficult to understand or interpret (S33: $\bar{x}$ = 72), as a direct result of participating in the training. Respondents seemed to overall neither agree nor disagree (S51: $\bar{x}$ = 47) when asked whether they would need to learn or understand more about OA or MCC before making any changes in how they address OA issues on the job.

When asked the open-ended question, "What, if anything, do you see as the missing piece(s) that would help solidify your learning about ocean acidification or marine carbonate chemistry?", respondents felt strongly that more "big picture" context to OA issues was one of the key missing pieces. Another common theme was an increase in time to review and repeat what they had learned, along with opportunities to apply it. These same themes were also prominent, along with an interest in collaborating with knowledgeable partners on their projects, when asked, "What do you see as the next step in your learning about this?".

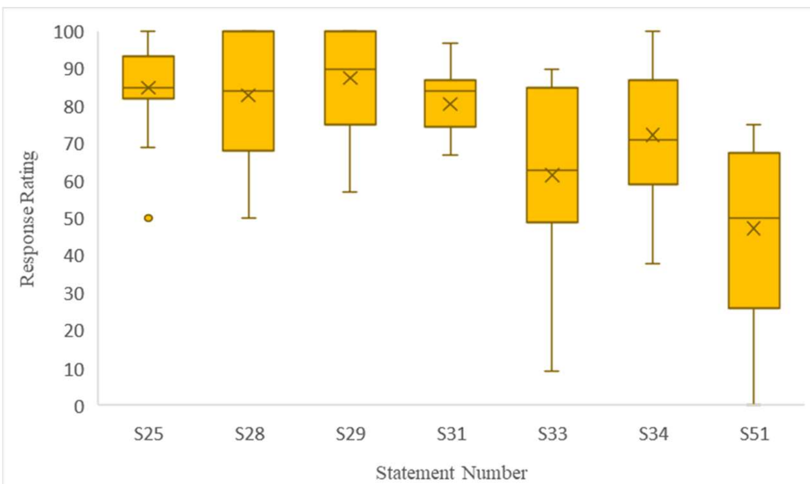

Figure 2.4 Long-term learning outcomes.
Box-and-whisker plot of follow-up (t2) survey responses to key statements about perceptions and changes in learning as a direct result of participating in the workshop (n = 18).

Confidence

Several key statements assessed changes in workshop participant post-training confidence as a direct result of training participation (Figure 2.5). Results of reliability analysis (α = .911) indicated good internal consistency for these measures as a single latent concept. These statements measured respondents' confidence in what they know about OA and MCC (S30, $\bar{x}$ = 79), their ability to talk about it with others (S43, $\bar{x}$ = 72, S44, $\bar{x}$ = 70), and their ability to measure MCC variables (S52, $\bar{x}$ = 77). When asked, "Why do you think it was difficult to get accurate results?” with regard to the measurement tasks in lab, respondents strongly agreed that the difficulty in obtaining accurate results was largely due to their lack of familiarity with procedures and instrumentation but expressed confidence in their ability to improve their results. When asked in what role they see themselves best able to contribute to OA (measuring, monitoring, managing, or mitigating), half of respondents selected more than one option. Monitoring was shared by 61% of respondents, followed by managing (39%), measuring (28%), and mitigating (11%). Respondents supported this with moderate agreement ($\bar{x}$ = 77, S.D. = 10) when prompted with, “I have a better idea of what resources or activities to focus on when it comes to my role in measuring, monitoring, mitigating, or managing OA”, as a direct result of participating in the workshop.

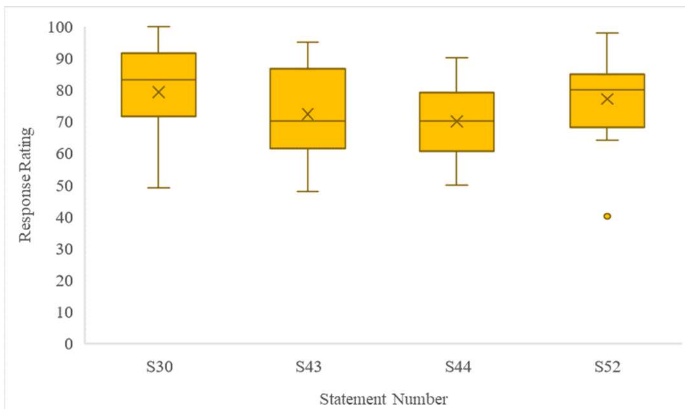

Figure 2.5 Change in confidence.
Box-and-whisker plot of follow-up (t2) survey responses to statements assessing changes in participant confidence as a direct result of participating in the workshop (n = 18).

Understanding Professional Behavior

As a direct result of participating in the workshop, participants reported general agreement that the way they talk about OA ($\bar{x}$ = 66) and MCC ($\bar{x}$ = 67), had changed. Respondents expressed that the complexity and challenges of accurate and precise measurement are what stuck with them the most when asked, and this theme is reflected in changes in the way they talk about it with others as a result of the workshop. Respondents frequently communicated that while they felt more confident in their understanding, they believe measurement tasks are better left to more knowledgeable experts with whom they wish to collaborate. Several also noted that the ability to calculate and constrain the carbonate system was novel information to them, and a key piece of information that stood out. A stronger sense of urgency to address the OA problem was a common theme reported in how their communication behaviors had changed.

Agreement was inconsistent however for changes in other behaviors (Figure 2.6), such as whether they were considering altering projects or procedures at work (S47 & 48), making changes to responsibilities (S50), or thinking about changing the way in which they work with instrumentation (S53), acquiring new equipment (S55), or altering their instrumentation and data needs (S58). Respondents see one of the most important changes necessary to address these issues as the establishment of coastwide monitoring efforts and facilities where they can send samples for processing- a finding congruent with Boehm et al. (2015). The top needs mentioned are the presence of staff with expertise in MCC or easy access to someone who does, and the need for additional support from their employers in the form of funding and directives to perform related projects.

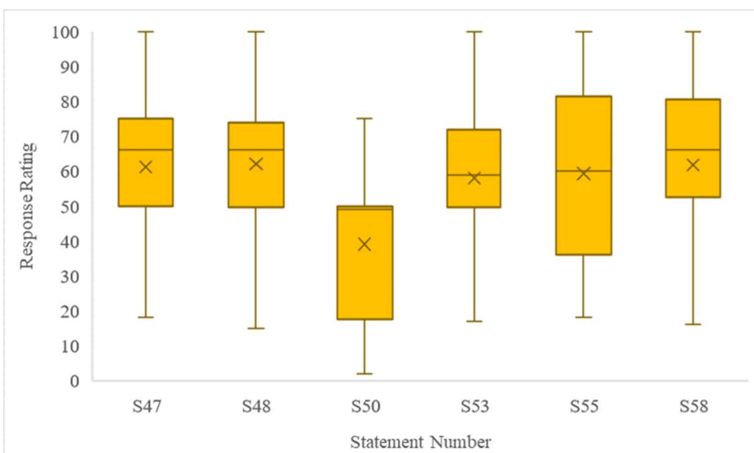

Figure 2.6 Change in professional behavior.
Box-and-whisker plot of follow-up (t2) questionnaire responses to statements assessing changes in participant behaviors on the job, as a direct result of participating in the training (n = 18).

DISCUSSION

PARTICIPANT KNOWLEDGE

The marine resource managers who participated in this study demonstrated moderate agreement in their perceptions of their own understanding of OA and MCC. Respondents who also participated in the workshop generally agreed that they understood OA, and this perception remained relatively unchanged by the training, despite significant increases in perceptions of their understanding of MCC. Several participants indicated that prior to the training they likely over-estimated confidence in their knowledge of OA, and that their post-training responses are likely more realistic assessments of this knowledge. As one participant put it,

> *"Before this workshop, I believe I thought I knew more than I did about ocean acidification, particularly carbonate chemistry and how to measure the 4 variables… In the pre-workshop survey and here, I put what I *thought* was true. I have much more confidence in my answers this time."*

Respondents provided initially tepid agreement ratings with statements about their understanding of MCC and how to measure it. The results of the survey suggest that this can be increased significantly using targeted hands-on professional development training. Results from the factual knowledge assessment questions about the marine carbonate system help validate these increases. Factual knowledge questions 20, 21, and 22 tested key pieces of information about MCC measurement and respondents demonstrated meaningful learning gains as a result of the training through significant increases in correct responses. Half of respondents correctly answered question 19 which tested their knowledge of the inorganic carbon species, but this result did not change in the post-training questionnaire, likely indicating some difficulty with the information or a shortcoming in instruction or questionnaire design. Respondents had relatively high incoming knowledge with regard to questions 15, 17, and 18, which likely overlap with information they have gained through other educational or professional experiences, leaving little room for improvement. The topic of carbon pumps (question 16) was touched on briefly in one of the webinars, which only half of the participants attended, and respondents understandably demonstrated the lowest learning gains for this question. Incoming knowledge of alkalinity was low with regard to question 23 which demonstrated relatively small post-training learning gains, indicating either it was insufficiently covered during instruction, or remained a conceptual stumbling block for many.

Despite indications of possible instructional shortcomings, it is clear that respondents experienced large positive changes in their factual knowledge of measuring the marine carbonate system. When asked what information stuck with them the most from the training, a majority reported a better understanding of the extent and complexity of the carbonate system and the challenges presented by obtaining accurate measurements, and felt they now had a better understanding of what is possible to know. This represents higher-order thinking of the concepts presented, which is an important outcome in education and training programs as it can be an important predictor of performance (Schneider & Artelt, 2010). This higher-order thinking was also reflected in their relatively strong agreement with statement 25 ("I have encountered or identified gaps in my knowledge that I would not have previously recognized") and can lead to individuals performing tasks more efficiently and effectively (Pressley et al., 2010).

Experiential Learning

The aims of providing a hands-on, experiential education program are to reinforce concepts through practical application (Knobloch, 2003), and frequently to motivate learners to action. In an effort to determine effectiveness of the experiential learning components, respondents were asked what they liked best about the workshop, with equal shares reporting lectures, laboratory sessions, and the ability to network with other professionals. Respondents reported lectures as useful for understanding the context of the OA problem and learning details of the chemistry, while labs were crucial to applying and ingraining this understanding. Lecture learning was well received, and in particular the first lecture on MCC which was viewed as helping them make better management decisions and improving their ability to communicate about these issues with the public.

> *"It allows me to understand the technical aspects of what is needed to get a handle on ocean carbonate chemistry, which will help me better evaluate information that others collect, proposals to monitor OA or if I were to undertake a data collection process for monitoring."*

While the lecture learning helps provide context and necessary information for their understanding, the key steps in the learning cycle of active experimentation and concrete experience were performed in laboratory sessions. Respondents reported that performing the hands-on tasks in lab helped establish stronger conceptual connections in their minds, specifically regarding how they think about relevant OA impact thresholds and how they are influenced by rates of change of the carbonate system. There was strong agreement among respondents that the lab sessions were vital to their learning and helped solidify understanding of what they were measuring, how it is measured, and the difficulties with obtaining accuracy, reducing uncertainty, and constraining the system. They reported that performing the lab tasks helped reinforce and solidify the ideas presented in lecture. All respondents viewed the lab sessions as a good and valuable contributor to their learning experience.

> *"The lab sessions made a vital contribution to my understanding of the marine carbonate system. I would not teach this material without including the lab sessions. In particular, running the tests on samples collected from participants local waters was a great idea, and contributed to my experience by motivating me to do my best to perform the tests accurately. I was interested in and invested in the outcome!"*

> *"The lab sessions provided the opportunity to gain a hands-on experience with the difficulties and power of making original measurements of the seawater parameters necessary to characterize the OA status of seawater samples that are relevant to my job."*

Participants also expressed meeting and interacting with colleagues and instructors as not only enjoyable and highly valuable, but also useful to reinforcing their understanding and facilitating future opportunities for collaboration. Transferring knowledge from scientists to managers can be more effectively facilitated by working to build strong relationships with managers to facilitate transfer of knowledge (Roux et al., 2006; Ryan & Cerveny, 2011), particularly the more that information is accessible, practical, and reflects what an expert knows (Kocher et al., 2012; Ryan & Cerveny, 2011).

Self-Efficacy

Individuals who are more likely to engage in a behavior are said to possess higher self-efficacy (Bandura, 1977) and confidence is a key component of this construct (Bandura, 1997; Stajkovic, 2006). To better understand how to design informal learning programs to increase learner self-efficacy, we assessed confidence measures and potential barriers to action. Respondents who attended our training strongly agreed that the difficulty in obtaining accurate results in lab was largely due to lack of familiarity with the procedures and instrumentation presented and expressed confidence in their ability to improve their results if given future opportunities.

Our participants indicated several ways in which they view themselves as capable of addressing the OA problem, and expressed indications of behavioral changes as a result, particularly regarding changes to the way they communicate about OA. Respondents expressed strong interest in knowing how to talk about OA and MCC more knowledgeably, especially when it comes to interacting with the public and their stakeholders. A majority view themselves as having a role, or more than one role, in addressing these issues, collectively envisioning themselves in positions to contribute to all levels of management and decision-making. The most frequently mentioned role they envision themselves taking is that of monitoring. Respondents see one of the most important changes necessary to address these issues as the establishment of coastwide monitoring efforts and facilities where they can send samples for processing. They were typically less interested in acquiring instrumentation and performing measurements on their own, and more interested in networking with those who already have MCC expertise. This could take the form of cross-agency collaborations and with subject matter specialists to improve and increase research and monitoring efforts and facilitate putting instrumentation in the hands of the people with proper expertise. Future efforts could take advantage of this interest to promote post-training collaboration and improve knowledge retention. Belonging to a professional community of practice is a strong indicator of whether an individual will retain and utilize information gained in a professional development workshop (Loucks-Horsley, 1996).

When asked what barriers exist to achieving these goals, lack of funding was overwhelmingly seen as the primary barrier to these accomplishments. Lack of availability of MCC experts was also frequently cited as a barrier, as well as lack of recognition of the

OA problem, particularly of its urgency, among their employers and the public. A secondary concern was that even though their knowledge and abilities enabled them to perform some of these functions, they were constrained by the limitations of their job duties. They also expressed the need for additional support from their employers in the form of directives to perform projects related to OA monitoring.

> *"I think it would be great to set up a monitoring OA network where people such as myself routinely collect water samples to be processed in proper labs for OA, and these data are put in a central repository. Over time we will build a seasonal, interannual, and spatial dataset that all can access."*

The quote above captures an oft-repeated lament by our participants, which is in line with the findings of Boehm et al. (2015), who identified the most common need to assist coastal resource managers with integrating OA into their work as the implementation of comprehensive coastal monitoring programs. Our participants have already expressed their confidence and abilities to shoulder the duties of responding to OA, but the barriers above will be certain to stymie their efforts if left unaddressed.

LIMITATIONS

This study featured a limited sample of marine resource managers from a single region, and future studies would benefit from broader survey coverage to make more generalizable claims about marine resource managers as a population. Similarly, the logistic realities of conducting a professional development training program necessitate relatively small class sizes, and when combined with the difficulties of achieving consistent survey response rates, similar studies are likely to yield datasets that may be too small to effectively answer evaluators' questions. Although the original intention was to demonstrate the effectiveness of the hands-on experiential learning components of the training, the small size of the dataset did not allow for that level of analysis. Participants in future trainings would benefit from periodic, repeated, short-run training programs to solidify their learning, which would also have the added benefit of yielding more consistent survey data to help evaluate training efforts as well as participant needs more precisely and effectively. Like other complex science topics, there are relatively few evaluation tools available to researchers and evaluators to quickly identify the appropriate components of factual and conceptual knowledge in MCC that would easily discriminate between expert and non-expert knowledge. As part of this study, but not reported here, a concept mapping activity with experts and non-experts was piloted to help identify differences in conceptual and factual knowledge, but more work is required on the conceptual structure and learning pathways related to MCC and OA.

CONCLUSIONS

This study investigated the perceptions and knowledge of OA and MCC of marine resource managers, and how a professional development training program can alter them and influence management behaviors and decision-making. While many marine resource managers view themselves as confident and capable of making important contributions to tackling OA issues, they see a crucial role for OA experts in the process and feel hampered by logistical barriers such as limited funding and an under-prioritization of OA monitoring which may ultimately prevent implementation (Cooley et al., 2015).

The outcomes and feedback from our participants can help improve understanding of the knowledge gaps associated with this critical topic (Gattuso et al., 2013; Volmert et al., 2013), and can help inform how to adapt management and training strategies for the future. In the face of changing environmental conditions, marine resource managers are likely to increasingly find themselves needing to make shrewd management decisions with regard to their time and efforts, using the science that is best available to them (Lester et al., 2010). These results can help us better understand how to connect managers with this information, which may be facilitated through strong relationships between scientists and managers (Kocher et al., 2012; Roux et al., 2006; Ryan & Cerveny, 2011).

Possessing a clear understanding of the system driving the impacts of OA is likely to aid managers' ability to respond (Cone & Winters, 2013; Ryan & Cerveny, 2011). Adaptation to future conditions will likely benefit from progressive and continual professional development on topics that have traditionally been reserved as niche information for research scientists. This will rely on connections with subject matter specialists who are in a position to disseminate advances in scientific understanding and technological developments related to the issue, which is an effective method of facilitating learning (Roux et al., 2006). Achieving the intended outcomes from a professional development training program depends on the way in which knowledge is delivered to a particular audience (Cone & Winters, 2013; Fazey et al., 2014), and incorporating participant feedback early on into program designs can help shape this delivery. Our participants have expressed a desire for continued and repeated training to maintain the freshness of their knowledge and keep them up-to-date on the latest science. Marine resource managers understand the need to deal with future problems using solutions designed for the future and delivering educational programs that are vetted and timely equips them with the tools necessary to develop these solutions.

References

Arnold, T., Mealey, C., Leahey, H., Miller, A. W., Hall-Spencer, J. M., Milazzo, M., & Maers, K. (2012). Ocean acidification and the loss of phenolic substances in marine plants. *PLoS one, 7*(4), e35107.

Auerbach, C., & Silverstein, L. B. (2003). *Qualitative data: An introduction to coding and analysis*: NYU press.

Bandura, A. (1977). Self-efficacy: toward a unifying theory of behavioral change. *Psychological review, 84*(2), 191.

Bandura, A. (1997). *Self-efficacy: The exercise of control*: Macmillan.

Barton, A., Hales, B., Waldbusser, G. G., Langdon, C., & Feely, R. A. (2012). The Pacific oyster, Crassostrea gigas, shows negative correlation to naturally elevated carbon dioxide levels: Implications for near-term ocean acidification effects. *Limnology and oceanography, 57*(3), 698-710.

Birman, B. F., Desimone, L., Porter, A. C., & Garet, M. S. (2000). Designing professional development that works. *Educational leadership, 57*(8), 28-33.

Boehm, A. B., Jacobson, M. Z., O'Donnell, M. J., Sutula, M., Wakefield, W. W., Weisberg, S. B., & Whiteman, E. (2015). Ocean acidification science needs for natural resource managers of the North American west coast. *Oceanography, 28*(2), 170-181.

Briñol, P., & DeMarree, K. (2012). *Social metacognition*: Psychology Press.

Bybee, R. W. (1990). Science for life & living: An elementary school science program from biological sciences curriculum study. *The American Biology Teacher, 52*(2), 92-98.

Capstick, S. B., Pidgeon, N. F., Corner, A. J., Spence, E. M., & Pearson, P. N. (2016). Public understanding in Great Britain of ocean acidification. *Nature Climate Change, 6*(8), 763.

Cone, J., & Winters, K. (2013). Planning and evaluating science video programs using communication science. *Journal of Applied Communications, 97*(4), 9.

Cooley, S. R., Jewett, E. B., Reichert, J., Robbins, L., Shrestha, G., Wieczorek, D., & Weisberg, S. B. (2015). Getting ocean acidification on decision makers' to-do lists: dissecting the process through case studies. *Oceanography, 28*(2), 198-211.

Dillman, D. A. (1978). *Mail and telephone surveys: The total design method* (Vol. 19): Wiley New York.

Doney, S. C., Balch, W. M., Fabry, V. J., & Feely, R. A. (2009). Ocean acidification: a critical emerging problem for the ocean sciences. *Oceanography, 22*(4), 16-25.

Duran, L. B., & Duran, E. (2004). The 5E Instructional Model: A Learning Cycle Approach for Inquiry-Based Science Teaching. *Science Education Review, 3*(2), 49-58.

Enochs, L. G., & Riggs, I. M. (1990). Further development of an elementary science teaching efficacy belief instrument: A preservice elementary scale. *School science and mathematics, 90*(8), 694-706.

Fazey, I., Bunse, L., Msika, J., Pinke, M., Preedy, K., Evely, A. C., . . . Reed, M. S. (2014). Evaluating knowledge exchange in interdisciplinary and multi-stakeholder research. *Global Environmental Change, 25*, 204-220.

Feely, R. A., Alin, S. R., Carter, B., Bednaršek, N., Hales, B., Chan, F., . . . Byrne, R. H. (2016). Chemical and biological impacts of ocean acidification along the west coast of North America. *Estuarine, Coastal and Shelf Science, 183*, 260-270.

Feely, R. A., Sabine, C. L., Lee, K., Berelson, W., Kleypas, J., Fabry, V. J., & Millero, F. J. (2004). Impact of anthropogenic CO2 on the CaCO3 system in the oceans. *Science, 305*(5682), 362-366.

Gattuso, J.-P., Mach, K. J., & Morgan, G. (2013). Ocean acidification and its impacts: an expert survey. *Climatic Change, 117*(4), 725-738.

Hales, B., Takahashi, T., & Bandstra, L. (2005). Atmospheric CO2 uptake by a coastal upwelling system. *Global biogeochemical cycles, 19*(1).

Harley, C. D., Randall Hughes, A., Hultgren, K. M., Miner, B. G., Sorte, C. J., Thornber, C. S., . . . Williams, S. L. (2006). The impacts of climate change in coastal marine systems. *Ecology letters, 9*(2), 228-241.

Knobloch, N. A. (2003). Is experiential learning authentic? *Journal of Agricultural Education, 44*(4), 22-34.

Kocher, S. D., Toman, E., Trainor, S. F., Wright, V., Briggs, J. S., Goebel, C. P., . . . Steelman, T. A. (2012). How can we span the boundaries between wildland fire science and management in the United States? *Journal of Forestry, 110*(8), 421-428.

Kolb, D. A. (1984). Experience as the source of learning and development. *Upper Sadle River: Prentice Hall*.

Lester, S. E., McLeod, K. L., Tallis, H., Ruckelshaus, M., Halpern, B. S., Levin, P. S., . . . Costello, C. (2010). Science in support of ecosystem-based management for the US West Coast and beyond. *Biological Conservation, 143*(3), 576-587.

Liu, X., Byrne, R. H., Lindemuth, M., Easley, R., & Mathis, J. T. (2015). An automated procedure for laboratory and shipboard spectrophotometric measurements of seawater alkalinity: Continuously monitored single-step acid additions. *Marine Chemistry, 174*, 141-146.

Loucks-Horsley, S. (1996). Principles of Effective Professional Development for Mathematics and Science Education: A Synthesis of Standards. *NISE brief, 1*(1), n1.

Maxwell, J. A. (2012). *Qualitative research design: An interactive approach* (Vol. 41): Sage publications.

Miles, M. B., Huberman, A. M., Huberman, M. A., & Huberman, M. (1994). *Qualitative data analysis: An expanded sourcebook*: sage.

Miller, J. J., Maher, M., Bohaboy, E., Friedman, C. S., & McElhany, P. (2016). Exposure to low pH reduces survival and delays development in early life stages of Dungeness crab (Cancer magister). *Marine Biology, 163*(5), 118.

Molenberghs, P., Trautwein, F.-M., Böckler, A., Singer, T., & Kanske, P. (2016). Neural correlates of metacognitive ability and of feeling confident: a large-scale fMRI study. *Social cognitive and affective neuroscience, 11*(12), 1942-1951.

Pierrot, D., Lewis, D., & Wallace, D. (2006). CO2SYS. EXE—MS excel program developed for CO2 system calculations. ORNL/CDIAC-105a: Carbon dioxide Information center, Oak RidgeNational laboratory, US ….

Pressley, M., Borkowski, J. G., & Schneider, W. (2010). Cognitive strategies: Good strategy users coordinate metacognition and knowledge.

Roux, D. J., Rogers, K. H., Biggs, H., Ashton, P. J., & Sergeant, A. (2006). Bridging the science-management divide: Moving from unidirectional knowledge transfer to knowledge interfacing and sharing.

Ryan, C. M., & Cerveny, L. K. (2011). Wildland fire science for management: Federal fire manager information needs, sources, and uses. *Western Journal of Applied Forestry, 26*(3), 126-132.

Schneider, W., & Artelt, C. (2010). Metacognition and mathematics education. *ZDM, 42*(2), 149-161.

Stajkovic, A. D. (2006). Development of a core confidence-higher order construct. *Journal of Applied Psychology, 91*(6), 1208.

Vaske, J. J. (2008). *Survey research and analysis: Applications in parks, recreation and human dimensions*: Venture Pub.

Volmert, A., Baran, M., Kendall-Taylor, N., Lindland, E., Haydon, A., Arvizu, S., & Bunten, A. (2013). Just the Earth doing its own thing": Mapping the gaps between expert and public understandings of oceans and climate change. *Washington, DC: FrameWorks Institute*.

Waldbusser, G. G., Hales, B., Langdon, C. J., Haley, B. A., Schrader, P., Brunner, E. L., . . . Gimenez, I. (2015). Saturation-state sensitivity of marine bivalve larvae to ocean acidification. *Nature Climate Change, 5*(3), 273.

CHAPTER 3 SECOND MANUSCRIPT [NMEA *CURRENT*]

OCEAN ACIDIFICATION FOR MARINE RESOURCE MANAGERS: A SUMMARY TEACHING AND EVALUATION FRAMEWORK

ABSTRACT

Ocean acidification (OA) is often considered only as a change in acidity (pH), but the reality involves a series of alterations to seawater chemistry that are not always easy to understand or measure. Gaining a deeper understanding of the mechanisms behind these dynamic environmental changes, and how to measure and interpret them in context, is becoming increasingly important for management decision-making and adaptation to future changes. To address this need, we draw from results of a pilot study of marine resource management professionals and offer a summary training framework grounded in educational and social science theory for teaching and evaluating OA chemistry and measurement.

INTRODUCTION

Ocean acidification (OA) is a complex anthropogenically-driven environmental issue that is anticipated to impact many ecologically, economically, and socially important marine organisms (Doney et al., 2009; Orr et al., 2005; Waldbusser et al., 2015). Effective management responses to OA will require generalized understanding of the seawater chemistry mechanisms behind these environmental changes and is becoming increasingly important for marine resource managers to feel prepared to respond to future changes. Many of these OA 'first responders' have expressed the need for the information and skills necessary for effective decision-making (Boehm et al., 2015), but few if any such programs have been offered, leaving many in a position to either take no action, or take improper or insufficient action towards handling OA issues. Results from a pilot training effort focused on conceptual understanding and measurement of OA indicate that this need can be partially fulfilled through carefully designed, delivered, and evaluated professional development training (CHAPTER 2).

A handful of research studies have been conducted on the understanding of OA among different audiences (Capstick et al., 2016; Danielson & Tanner, 2015; Gattuso et al., 2013; Volmert et al., 2013), and how to teach it (Erickson, 2018a; Fauville et al., 2013), but none have yet focused on the marine carbonate chemistry (MCC) system that drives it. Understanding the most effective ways to teach this novel content to a new audience will likely require a strong reliance on educational and social science theory to achieve desired outcomes. Following the Understanding by Design scheme of working backwards from identifying learning goals, consideration of assessment and evaluation, and development of a learning plan (Wiggins et al., 2005), we designed a training program for marine resource managers to develop a working understanding of MCC dynamics and measurement as it relates to OA. The design utilizes the 5E learning cycle of engagement, exploration, explanation, elaboration, and evaluation (Bybee, 1990) to facilitate hands-on, experiential learning through active participation, which is an effective method to enhance learning and confidence in informal adult science education programs (Duran & Duran, 2004). Hands-on training programs seek to not only cement knowledge and skills through authentic learning activities, but also to influence the behavioral intentions of the learners, which can be achieved through changes in understanding and confidence (Bandura, 1977). Ultimately, the goal of offering a training program is to induce some change in professional behavior through implementation of the knowledge and skills obtained, and the way in which educational programs are structured can facilitate these outcomes and evaluation of the effectiveness of educators' efforts (Fazey et al., 2014).

This paper presents a professional development training framework that science educators can follow to help marine resource managers construct a working understanding of MCC dynamics and measurement as it relates to OA, that may in-turn empower them toward more salient and effective management decision-making. This training was designed and tested in a pilot study conducted at Hatfield Marine Science Center in Newport, Oregon, in 2018. Participants reported improvements in their understanding of MCC and viewed working hands-on with instrumentation as the key component of this shift. Long-term outcomes showed many had altered their professional decision-making processes, the way they reported OA-related issues in publications, and the way they talk about the subject with peers, stakeholders, and the public. These behavioral changes were accompanied by increases in perceptions of confidence and their knowledge of OA, and clearer conceptions of their remaining learning needs. The outcomes and feedback from these foundational efforts contribute to understanding the knowledge gaps associated with this critical topic (Gattuso et al., 2013; Volmert et al., 2013), and help inform how to adapt management and training strategies for the future. In the face of changing environmental conditions, marine resource managers are increasingly finding themselves having to make shrewd management decisions with regards to their time and efforts, using the science that is best available to them (Lester et al., 2010). Carefully designed training programs can enhance the ability of managers and other audiences to connect with this information, so they can better understand what is driving the system and respond more effectively.

A HANDS-ON, EXPERIENTIAL LEARNING PROGRAM

GOALS AND DESIRED OUTCOMES

The training framework presented in this paper seeks to positively change participant knowledge of the marine carbonate system and how to measure it, with the intent to positively influence management decision-making and practical implementation. The primary learning goals are for participants to retain long-term understanding of what is required to measure carbonate system parameters, and how to interpret first-order dynamics of the marine carbonate system. The big ideas the training focuses on are: 1) OA is not just about a change in pH – changes in other important chemistry parameters are happening as well, 2) impacts associated with these changes are dependent on organism and process, and 3) characterizing the system and understanding these effects requires measurement of at least two carbonate system parameters.

ASSESSMENT AND EVALUATION

Participant assessment occurs primarily through a series of laboratory-based performance tasks, each followed by guided discussions to facilitate critical thinking on measurement procedure and interpretation and comparison of results. Laboratory tasks build on one another conceptually, promote development of practical skills for carbonate chemistry measurement, and are an opportunity for participants to demonstrate their understanding to instructors and peers. The iterative nature of this design engages participants in exploration of concepts, explanation of their learning, and elaboration of their understanding - key components of the learning cycle (Bybee, 1990).

Evaluation of the program and participant outcomes is conducted via survey (APPENDIX A: SURVEY) using a pre-post format, and collecting participant concerns, interests, and suggestions from the pre-training questionnaire to help shape program design. A follow-up questionnaire delivered approximately three months post-training allows sufficient time to capture how participants have utilized skills and information they learned, and any other behavioral implementations. Educators are encouraged to develop evaluations that suit their needs and that of their audience, to improve knowledge and behavioral outcomes, and refine educational efforts. Those looking for further assistance in developing and evaluating surveys may refer to Diamond et al. (2016).

FORMAT

The training is structured as a professional development workshop to be run in approximately 1.5 days, but is amenable to other formats, and consists of four core academic lecture topics, followed by hands-on laboratory sessions which account for the majority of scheduled instructional time. Hands-on laboratory learning is an effective method for improving learner retention and confidence (Knobloch, 2003; D. A. Kolb, 1984). Ideally, educators will have access to wet-laboratory facilities with flow-thru seawater plumbing available, and collaborations with seawater chemistry specialists at universities and marine research stations are highly encouraged to provide the necessary expertise, facilities, and equipment. For a professional audience especially, it is recommended to conduct repeat trainings once or twice per year to improve retention and understanding and facilitate collaborations and broader participation.

LECTURES

Four primary lecture topics provide the context and content necessary for understanding interpretation and measurement of the marine carbonate system (Table 3.1). Context Lectures help participants understand environmental and organismal relationships with the OA problem, and some of the mechanisms of impacts that have been observed or may be anticipated. Core Content Lectures focus on learning the dynamics of the marine carbonate system, and the different ways in which its parameters are measured. Instructors may be tempted to utilize webinars to deliver lecture content, which has been shown to be an effective learning tool to reach broad audiences (Verma & Singh, 2009, 2010), but should be cautioned against doing so without dedicated assistance from experienced technology assistants.

Table 3.1 Workshop lecture breakdown.
Suggested lecture topics, big ideas, essential questions, and enduring understandings covered by each.[1]

		Big Ideas	Essential Questions	Enduring Understandings
Context	Lecture 1: Biological Impacts of OA	• OA has multiple modes of action • Impacts depend greatly on organism and process	What is the scope of OA impacts on biological systems and organisms?	• Impacts occur at multiple scales from species to ecosystems • Impacts occur in a multi-stressor context • Trends and thresholds can be defined • Scope for acclimation and adaptation varies
Context	Lecture 2: The Carbon Cycle	• The cause of OA is well known • Processes that transfer C between reservoirs have differential impacts • The OA perturbation affects the system in a variety of ways	What drives variability in ocean carbonate chemistry?	• Global carbon budgets are well-constrained • Natural processes and how they shape OA variability • Shifts in carbonate system parameters result in multiple organism-relevant responses
Content	Lecture 1: Marine Carbonate Chemistry	• The parameters, relationships, and dynamics of the carbonate system in seawater • Processes that adjust one parameter result in instantaneous readjustment of the others • These relationships and adjustments can be calculated	What comprises the marine carbonate system, and how does it work?	• The four measurable carbonate system parameters: pH, TCO_2, pCO_2, TA • Only two are required to constrain the entire system • Salinity and temperature are required ancillary variables • Omega is a management relevant, but not measurable, parameter
Content	Lecture 2: Measurement	• Multiple methods exist to measure each parameter • Some are harder to get right than others • Precision and accuracy depend on choices made	How do we measure the marine carbonate system?	• Methods for measuring carbonate system parameters • Importance of calibrations and reference materials • Biological responses may exist within chosen margins of precision and accuracy

[1] Big Ideas, Essential Questions, and Enduring Understandings format taken from Wiggins et al. (2005).

Labs

Table 3.2 Contents for discrete seawater sampling kits
• Cleaned, acid-washed crown-cap amber bottles • Bottle capper • Bottle caps • Saturated mercuric chloride (HgCl) solution in 4mL dropper bottle • 3mL disposable transfer pipette • pH sensor with integrated temperature probe[1] • sampling instructions
[1] Temperature sensors may be provided separately if not integrated into pH sensors

The hands-on, experiential learning components of the workshop allow participants to explore the relationships, dynamics, and measurement of the marine carbonate system. Laboratory tasks are framed as "challenges" to be completed in pairs or small groups to facilitate peer evaluation and communication between learners. The ideal laboratory setup features several stations that include a variety of off-the-shelf pH sensors, a tank of ultra-pure N_2 gas, and a variety of high-level oceanographic instruments to measure carbonate system parameters such as those manufactured by Sunburst Sensors and Sea-bird Scientific. The basic pH sensors should come equipped with integrated temperature sensors, or temperature sensors can be provided separately, and participants provided NIST-certified or NIST-traceable buffers for calibrations. For a full list of setup and supplies, see APPENDIX E: LABORATORY SETUPS AND PROCEDURES.

Carbonate calculations. The first laboratory session is a calculations exercise, in which participants work through a series of tasks in pairs or small groups with a carbonate system calculator such as CO2SYS (Pierrot et al., 2006). These tasks should challenge participants to understand how carbonate system parameters vary with one another under different conditions, to help build their conceptual understanding of the relationships and dynamics of the system. A list of these lab challenges is provided in APPENDIX F: CARBONATE CALCULATION LAB CHALLENGES USING CO2SYS.

Discrete sample collection. Measurement tasks must be performed using preserved discrete seawater samples obtained either from natural sources or in-house flow-thru seawater if available. This method is affordable and follows standard protocols outlined in Dickson et al. (2007). Samples can be collected at any point in time, and we recommend having participants learn the protocol as part of the training. Alternatively, participants can be provided with discrete seawater sampling kits ahead of time (Table 3.2), with instructions for independent field sampling (APPENDIX D: DISCRETE WATER SAMPLE COLLECTION INSTRUCTIONS).

Simple carbonate chemistry measurements. Participants are first introduced to basic methods for measuring pH and titration alkalinity (TA), starting with how to calibrate off-the-shelf pH sensors using the buffers provided and apply corrections to pH measurements. Participants measure the pH of preserved discrete seawater samples and combine this data with pCO_2 and TCO_2 measurements provided by instructors (using advanced instrumentation described below) to calculate the rest of the carbonate system with a carbonate system calculator. Following this exercise, participants conduct a procedure to measure TA (APPENDIX G: ALKALINITY TITRATION PROCEDURE) adapted from Liu et al. (2015) to constrain the carbonate system and compare the differences between their results and the values provided by instructors. Participants should be encouraged to attempt multiple iterations to explore sources of error and compare the impacts of differences in accuracy of their results and precision of their instrumentation on carbonate system calculations. The purpose of these tasks is to a) equip participants with basic methods to measure and constrain the carbonate system, b) inform their understanding of the challenges in obtaining accurate/precise measurements, and c) reinforce ideas introduced in lecture and the carbonate calculations lab.

Advanced instrumentation. In this session, participants gain skills using advanced oceanographic instruments they are likely to encounter or use in the field, that make direct measurements of the carbonate system. Examples may include pCO_2/TCO_2 analyzers or spectrophotometric or industrial-grade ISFET pH sensors. The goal is to provide participants with experience making measurements of the carbonate system using high-level instrumentation. The primary challenge for participants is to explore constraining the carbonate system using the parameters and measurement methods of their choice, to understand and compare differences in accuracy, precision, and convenience. Instructors guide them through sampling procedures to obtain these measurements and familiarize them with instrument operation. Multiple iterations, combinations, and comparisons of carbonate system calculations are encouraged to be explored, as performed in the previous lab sessions.

ANTICIPATED OUTCOMES

Resource managers operate within an extensive framework of managers, scientists, technicians, stakeholders, and the public. Achieving broader goals in measuring, monitoring, managing, and mitigating OA requires facilitating partnerships across agencies and institutions. One of the benefits frequently reported by participants of the pilot training was the opportunity to interact with peers from different agencies and institutions about OA issues, learn about each other's projects, and discuss potential partnerships to tackle shared problems. One result of this was broad agreement about the need for comprehensive coast-wide monitoring for the state of Oregon, which is congruent with the findings of Boehm et al. (2015).

Inviting marine resource managers from a variety of sectors facilitates collaborations and common solution sharing and can have the added effect of enhancing participants' confidence in their ability to communicate about the problem with the public. For many, this is an integral duty to their position, but they often feel unsure of the depth of their own understanding of the mechanisms of the system. While the intention is not to turn them into expert chemists, the benefits of having a deeper conceptual understanding of these mechanisms allows them to speak more pointedly when needed, and better recognize the limits of their knowledge. Participants in the pilot training demonstrated this outcome, frequently mentioning an improvement in their ability to identify gaps in their knowledge about OA that previously would have gone unnoticed. By becoming more knowledgeable ambassadors for OA, they can enhance connections with the public and their stakeholders and garner further support for good management efforts.

LIMITATIONS

Many marine resource managers serve in roles where they can implement strategies to respond to the impacts of OA, but inspiring them to action will require changes in their perceptions of their knowledge and confidence, which are important components of self-efficacy (Bandura, 1977; Stajkovic, 2006). Science and technology-centered professional development programs can successfully address factors of self-efficacy (Tschannen-Moran & McMaster, 2009; Watson, 2006), but perceptions of external barriers such as funding, restrictions on job duties, or lack of broadscale support for action, may still ultimately prevent implementation (Cooley et al., 2015). While it will likely be important and useful to educators and participants to surface these barriers through the training and evaluation process, there is presumably little that educators can do to address them directly. However, carefully-crafted training programs may be more apt to influence participant perceptions and self-confidence toward some desired behavioral change, and this may ultimately inspire and motivate them to find ways around their barriers where possible.

SUMMARY

Science educators who wish to address complex anthropogenically-driven environmental issues like OA should consider offering professional training programs that focus on mechanism and process through hands-on, experiential learning. The training framework suggested here outlines the benefits and limitations of this approach and can improve participants' ability to understand their local marine environments, anticipate and adapt to changes more efficiently, and facilitate novel connections between management and other stakeholder groups. These groups may include other relevant learners such as scientists, technicians, industry partners, university students, citizen scientists, and others, who can address environmental and resource issues. Offering continual and evolving training on this topic can help build resilience into management ecosystems by supplying more people with the information necessary to interpret data in context, and make better decisions when it comes to measuring, monitoring, mitigating, and managing marine resources. Having the best available science at their disposal may endow marine resource managers with greater confidence in their decision-making processes, and their ability to correctly characterize the consequences of the explicit trade-offs at hand. Marine resource managers equipped with the right information enhance their ability to identify the limits of their knowledge, make more realistic assessments, adapt to current issues and impacts, and plan for future changes. This can help facilitate the implementation of resilient strategies for managing vital coastal resources into an uncertain future.

REFERENCES

Bandura, A. (1977). Self-efficacy: toward a unifying theory of behavioral change. *Psychological review, 84*(2), 191.

Boehm, A. B., Jacobson, M. Z., O'Donnell, M. J., Sutula, M., Wakefield, W. W., Weisberg, S. B., & Whiteman, E. (2015). Ocean acidification science needs for natural resource managers of the North American west coast. *Oceanography, 28*(2), 170-181.

Bybee, R. W. (1990). Science for life & living: An elementary school science program from biological sciences curriculum study. *The American Biology Teacher, 52*(2), 92-98.

Capstick, S. B., Pidgeon, N. F., Corner, A. J., Spence, E. M., & Pearson, P. N. (2016). Public understanding in Great Britain of ocean acidification. *Nature Climate Change, 6*(8), 763.

Cooley, S. R., Jewett, E. B., Reichert, J., Robbins, L., Shrestha, G., Wieczorek, D., & Weisberg, S. B. (2015). Getting ocean acidification on decision makers' to-do lists: dissecting the process through case studies. *Oceanography, 28*(2), 198-211.

Danielson, K. I., & Tanner, K. D. (2015). Investigating undergraduate science students' conceptions and misconceptions of ocean acidification. *CBE—Life Sciences Education, 14*(3), ar29.

Diamond, J., Horn, M., & Uttal, D. H. (2016). *Practical evaluation guide: Tools for museums and other informal educational settings*: Rowman & Littlefield.

Dickson, A. G., Sabine, C. L., & Christian, J. R. (2007). *Guide to best practices for ocean CO2 measurements*: North Pacific Marine Science Organization.

Doney, S. C., Balch, W. M., Fabry, V. J., & Feely, R. A. (2009). Ocean acidification: a critical emerging problem for the ocean sciences. *Oceanography, 22*(4), 16-25.

Duran, L. B., & Duran, E. (2004). The 5E Instructional Model: A Learning Cycle Approach for Inquiry-Based Science Teaching. *Science Education Review, 3*(2), 49-58.

Erickson, B. D. (2018a). Effects of Teaching Household Actions to Address Ocean Acidification on Student Knowledge and Attitudes.

Fauville, G., Säljö, R., & Dupont, S. (2013). Impact of ocean acidification on marine ecosystems: educational challenges and innovations. *Marine Biology, 160*(8), 1863-1874.

Fazey, I., Bunse, L., Msika, J., Pinke, M., Preedy, K., Evely, A. C., . . . Reed, M. S. (2014). Evaluating knowledge exchange in interdisciplinary and multi-stakeholder research. *Global Environmental Change, 25*, 204-220.

Gattuso, J.-P., Mach, K. J., & Morgan, G. (2013). Ocean acidification and its impacts: an expert survey. *Climatic Change, 117*(4), 725-738.

Knobloch, N. A. (2003). Is experiential learning authentic? *Journal of Agricultural Education, 44*(4), 22-34.

Kolb, D. A. (1984). Experience as the source of learning and development. *Upper Sadle River: Prentice Hall*.

Lester, S. E., McLeod, K. L., Tallis, H., Ruckelshaus, M., Halpern, B. S., Levin, P. S., . . . Costello, C. (2010). Science in support of ecosystem-based management for the US West Coast and beyond. *Biological Conservation, 143*(3), 576-587.

Liu, X., Byrne, R. H., Lindemuth, M., Easley, R., & Mathis, J. T. (2015). An automated procedure for laboratory and shipboard spectrophotometric measurements of seawater alkalinity: Continuously monitored single-step acid additions. *Marine Chemistry, 174*, 141-146.

Orr, J. C., Fabry, V. J., Aumont, O., Bopp, L., Doney, S. C., Feely, R. A., . . . Joos, F. (2005). Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature, 437*(7059), 681.

Pierrot, D., Lewis, D., & Wallace, D. (2006). CO2SYS. EXE—MS excel program developed for CO2 system calculations. ORNL/CDIAC-105a: Carbon dioxide Information center, Oak RidgeNational laboratory, US ….

Stajkovic, A. D. (2006). Development of a core confidence-higher order construct. *Journal of Applied Psychology, 91*(6), 1208.

Tschannen-Moran, M., & McMaster, P. (2009). Sources of self-efficacy: Four professional development formats and their relationship to self-efficacy and implementation of a new teaching strategy. *The elementary school journal, 110*(2), 228-245.

Verma, A., & Singh, A. (2009). *Leveraging webinar for student learning.* Paper presented at the 2009 International Workshop on Technology for Education.

Verma, A., & Singh, A. (2010). Webinar—Education through digital collaboration. *Journal of Emerging Technologies in Web Intelligence, 2*(2), 131-136.

Volmert, A., Baran, M., Kendall-Taylor, N., Lindland, E., Haydon, A., Arvizu, S., & Bunten, A. (2013). Just the Earth doing its own thing": Mapping the gaps between expert and public understandings of oceans and climate change. *Washington, DC: FrameWorks Institute*.

Waldbusser, G. G., Hales, B., Langdon, C. J., Haley, B. A., Schrader, P., Brunner, E. L., . . . Gimenez, I. (2015). Saturation-state sensitivity of marine bivalve larvae to ocean acidification. *Nature Climate Change, 5*(3), 273.

Watson, G. R. (2006). Technology professional development: Long-term effects on teacher self-efficacy.

Wiggins, G., Wiggins, G. P., & McTighe, J. (2005). *Understanding by design*: Ascd.

CHAPTER 4 CONCLUSION

MARINE CARBONATE CHEMISTRY FOR THE MASSES

The ultimate goal of this project was to empower marine resource managers with knowledge and skills to address ocean acidification (OA) issues more effectively. The approach used to do this was by testing the effectiveness of a pilot professional development workshop focused on the chemistry of OA. The implication of its success is that it leads to practical, real-world behavioral change to address OA issues. Effective education and training must have an achievement-focused mission built into it, directed toward the desired outcome of effective understanding that can be transferred to specific and realistic contexts and situations (Wiggins et al., 2005). However, educational design strategies to overcome learning obstacles and achieve understanding are unique to each discipline (Bransford et al., 2000), and chemistry (broadly) is traditionally a more difficult subject for learners (Herron, 1975; Sirhan, 2007), despite efforts to understand why (Nakhleh, 1992; Sirhan, 2007; Zoller, 1990). Developing successful strategies for teaching marine carbonate chemistry (MCC) will likely require iterative testing and refinement of instructional and evaluative methods to generate the most effective and efficient program designs.

The work summarized in this thesis offers perspective on what marine resource managers in the Pacific Northwest know about OA and the marine carbonate system, and how we might be able to design effective professional development training to empower them with knowledge and skills to address OA issues more effectively. While some literature exists describing perceptions and knowledge of OA broadly among different audiences, this work appears to be the first to address perceptions and knowledge of MCC specifically. Unsurprisingly, marine resource managers perceive their knowledge of OA to be relatively high, and its relevance to their jobs even higher. Despite a significant post-training increase in their factual knowledge and perceptions of their understanding of MCC, their perceptions of their understanding of OA in general remained roughly the same throughout the study, suggesting two possibilities: 1) our participants conceptually view OA as more than simply a problem of chemistry, and 2) they already possessed relatively high confidence in their abilities from the outset. If one or both are true, these should be reassuring indications of not only the capability of our audience as managers, but also the salience of developing MCC-based training tools.

While marine resource managers are the quintessential OA ‘first responders’, it is my hope that the flexible and modular nature of the training design presented in this thesis will be adapted for other audiences which fall under this umbrella. Many who work in scientific and educational fields are well-equipped to benefit from this knowledge and apply it to their work in research, industry, education, communication, outreach, and engagement. Those interested in developing these educational and training programs stand to benefit from relying on collaboration with those who possess relevant expertise – powerful partnerships which have been demonstrated to be highly effective at facilitating knowledge transfer (Roux et al., 2006) and addressing the impacts of OA (Barton et al., 2015). These collaborations can also work to reduce material redundancies and capitalize on information sharing across organizations with limited means (Avery, 2017; Imperial, 1999). Many of our participants expressed great interest in fostering ongoing collaborations with OA experts, and even mentioned the lack of these relationships as a potential barrier to their ability to address OA issues:

> *“Having done the hands-on work helps me understand carbonate chemistry better. But it also makes me realize that I would want to review things before engaging in a very technical detail-oriented discussion on the topic and that it might be best to divert exceptionally detail oriented questions to a technical expert in the carbonate chemistry system.”*

They demonstrated their confidence through increases in their understanding of and abilities to measure MCC, as well as their inclinations to independently seek out and interpret technical information as a direct result of the training. However, it should remain clear that the goal is not to turn participants into MCC experts themselves, but rather empower them to become more savvy practitioners, informed consumers, and discerning interpreters of OA information.

This initial attempt to craft effective MCC-centered informal education has yielded results that indicate progress toward this goal, but there remains much more work to be done. OA is a global issue of rapidly growing concern (Doney et al., 2009; Feely et al., 2004; Orr et al., 2005), and while increasing OA first responder knowledge of MCC will be crucial to tackling these issues, actions to address OA will extend beyond merely understanding the chemistry (Adelsman & Whitely Binder, 2012). Future education and training efforts should lean heavily on learning and educational design theory to alleviate conceptual difficulties and enhance learner engagement and retention. The use of carefully crafted formative assessments can help instructors monitor learning and tailor their strategies to address gaps in student knowledge (Bybee, 2002). Achieving successful educational outcomes is likely to require not just teaching what subject matter specialists and instructors think students need to know, but also engaging in fostering strong relationships through feedback, repetition, and discussion with learners to understand what they already know, want to know, and need to know.

Experiential Learning: Watering the Self-Efficacy Garden

The professional development workshop created for this research was intentionally constructed within a hands-on learning framework to facilitate increased participant understanding and retention and explore indicators of resultant behavioral change. These indicators are among the five essential components of self-efficacy (Bandura, 1977; Stajkovic, 2006), and could be used to gauge the broader impacts of similar training programs. Outcomes in participant perceptions and knowledge suggest the hands-on learning components were effective to some degree, however the tasks and procedures did come with some difficulties. While there were limitations to selecting a purposely homogeneous sample of professionals, one benefit of having such a group is that participants will be more likely to identify with one another. This is highly conducive to learning through vicarious experience, and participants expressed that meeting and interacting with their colleagues was not only enjoyable, but also useful for their understanding of MCC. These interactions can also help facilitate opportunities for networking and collaboration in addressing OA (Boehm et al., 2015).

Increases in direct measures of confidence were also reported by our participants as a result of attending the workshop (summarized in CHAPTER 2), which can be a strong indicator of their likelihood to act (Stajkovic, 2006). Indirect indications of changes in their confidence were present in how they expressed their behavioral changes or inclinations for such. These changes in behavior took on a variety of forms but appear limited to adjustments in personal behavior such as thinking and talking, rather than shifts in decision-making on the job. There are likely many factors contributing to this, among them the many external barriers reported by participants that can be surfaced and addressed in a training environment. While these barriers will be largely out of reach of any training program to resolve, effective training programs may empower participants to find ways to overcome or work around their barriers by equipping them with new knowledge, skills, and increased confidence – the beginnings of a recipe for action.

Oft-measured precursors to behavior are one's beliefs and attitudes, which were not measured in the course of this study. An *a priori* assumption was made that by electing to attend our training program our participants would have high incoming belief and attitude scores that would change little over the course of the training. However, the presence of outliers at times and the variety of intentions expressed for attending demonstrate that this may not exactly have been the case. The professionals we recruited all attended for different reasons, some of which may have excluded an interest in learning or retaining the chemistry. Indeed, select participants confirmed that the value of the workshop for them was more focused on broadening their perspective of the OA problem. Additionally, those who attend specifically to learn the chemistry, and those that learn the chemistry best may not always be the same individuals. Others may not want to learn the chemistry but feel obliged by the demands of their job description or some other sense of duty to do so, and this may also thwart their learning efforts. Future evaluators could benefit greatly from incorporating measures of participant beliefs and attitudes into their assessments to help refine program design and interpret outcomes in behavioral change.

REFINING FUTURE EDUCATIONAL EFFORTS: LESSONS LEARNED

As a pilot study, the scope and extent of applicability of this project are limited in their nature but provide a framework from which to build upon and test future hypotheses regarding teaching and learning MCC within the context of OA. Future efforts could utilize a quasi-experimental design with separate treatment and control groups subjected to varying levels and methods of instruction. This would allow future researchers and educators to isolate the effects of teaching each topic and component of the training program. Iterative training trials would also yield sufficient survey data for the analyses that could demonstrate these relationships, and highlight long-term impacts on knowledge, perceptions, and behavior. For example, the value and effectiveness of hands-on learning in this context could be better understood through comparisons between outcomes of learners who only participate in lecture learning versus those who participate in hands-on laboratory training in addition to lectures. Some educators may be tempted to utilize webinar delivery for lectures which can be an effective way to increase student learning if well-executed (Verma & Singh, 2009, 2010). However, we would caution this choice without vested guidance from experienced technology assistants. Our webinar experience was unfortunately beset with technical and user difficulties and may have negatively impacted participants' experience of those lectures. Well-crafted surveys could identify which concepts of the marine carbonate system are the most troublesome for learners and be used to construct more effective strategies to achieve long-term understanding. And while external barriers to action are beyond the reach of educators to provide solutions for, manifesting them in an educational setting that seeks to improve learner knowledge and confidence may lead to changes in how participants perceive their abilities to overcome them. While there were notable changes in perceptions and knowledge observed from these efforts, the ability to characterize the contributions of each aspect of the training to these changes was limited. The information presented in this thesis hopefully provides educators and researchers with a preliminary guide for how to construct future training programs that can answer questions about the value of the skills and knowledge required to address OA.

SUPPORTING OUR MARINE RESOURCE MANAGERS

The jobs of marine resource managers span a wide range of disciplines, interests, and responsibilities, and the individuals themselves represent an even broader range of experience and education. Generalizations about their needs and desires should be regarded with caution, but within the context of understanding MCC to address OA there is common ground to be found. As learners, they appear interested, motivated, capable, and willing to help. From literature and this study, the job of MCC experts and science educators seems clear then: to be available, accessible, and approachable, form collaborative partnerships to offer continuing support and work toward solutions, and deliver education and training that connects with their specific needs and interests.

The professionals that attended our training communicated that they view themselves positioned in roles to address the OA problem that include measuring, monitoring, managing, and mitigating its impacts, with a strong emphasis on monitoring. This encouraging feedback points to a resolve to realize their contributions, and experts and educators can utilize this information when strategizing training efforts. No program design will be perfect, but the use of repetition and follow-up assessments may allow educators to target the needs of their participants more effectively.

Support for continued training programs will require recognition and investments from the stakeholders and institutions invested in successful resource management outcomes. The perennial limitation will be funding, which is likely to only change once perceptions of urgency increase among legislators, industry, and the public (Cooley et al., 2015). However, one of the most effective ways that perception may change can be through efforts in education, outreach, and engagement, which are perhaps less likely to happen without OA professional development interventions for the very same marine resource managers who conduct those efforts. The question of what can ultimately be done about the OA problem lingers beyond the scope of this thesis but understanding how to create effective educational tools and their influence on real-world change may lead us to more powerful and practical management solutions to the impacts of OA.

References

Adelsman, H., & Whitely Binder, L. (2012). Ocean Acidifaction: From Knowledge to Action, Washington State's Strategic Response. *Washington State Blue Ribbon Panel on Ocean Acidification. Olympia, Washington Washington Department of Ecology*.

Avery, E. J. (2017). Public information officers' social media monitoring during the Zika virus crisis, a global health threat surrounded by public uncertainty. *Public Relations Review, 43*(3), 468-476.

Bandura, A. (1977). Self-efficacy: toward a unifying theory of behavioral change. *Psychological review, 84*(2), 191.

Barton, A., Waldbusser, G. G., Feely, R. A., Weisberg, S. B., Newton, J. A., Hales, B., . . . Jefferds, I. (2015). Impacts of coastal acidification on the Pacific Northwest shellfish industry and adaptation strategies implemented in response. *Oceanography, 28*(2), 146-159.

Boehm, A. B., Jacobson, M. Z., O'Donnell, M. J., Sutula, M., Wakefield, W. W., Weisberg, S. B., & Whiteman, E. (2015). Ocean acidification science needs for natural resource managers of the North American west coast. *Oceanography, 28*(2), 170-181.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn* (Vol. 11): Washington, DC: National academy press.

Bybee, R. W. (2002). *Learning science and the science of learning: Science educators' essay collection*: NSTA press.

Cooley, S. R., Jewett, E. B., Reichert, J., Robbins, L., Shrestha, G., Wieczorek, D., & Weisberg, S. B. (2015). Getting ocean acidification on decision makers' to-do lists: dissecting the process through case studies. *Oceanography, 28*(2), 198-211.

Doney, S. C., Balch, W. M., Fabry, V. J., & Feely, R. A. (2009). Ocean acidification: a critical emerging problem for the ocean sciences. *Oceanography, 22*(4), 16-25.

Feely, R. A., Sabine, C. L., Lee, K., Berelson, W., Kleypas, J., Fabry, V. J., & Millero, F. J. (2004). Impact of anthropogenic CO2 on the CaCO3 system in the oceans. *Science, 305*(5682), 362-366.

Herron, J. D. (1975). Piaget for chemists. Explaining what" good" students cannot understand. *Journal of Chemical Education, 52*(3), 146.

Imperial, M. T. (1999). Institutional analysis and ecosystem-based management: the institutional analysis and development framework. *Environmental management, 24*(4), 449-465.

Nakhleh, M. B. (1992). Why some students don't learn chemistry: Chemical misconceptions. *Journal of Chemical Education, 69*(3), 191.

Orr, J. C., Fabry, V. J., Aumont, O., Bopp, L., Doney, S. C., Feely, R. A., . . . Joos, F. (2005). Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature, 437*(7059), 681.

Roux, D. J., Rogers, K. H., Biggs, H., Ashton, P. J., & Sergeant, A. (2006). Bridging the science-management divide: Moving from unidirectional knowledge transfer to knowledge interfacing and sharing.

Sirhan, G. (2007). Learning difficulties in chemistry: An overview.

Stajkovic, A. D. (2006). Development of a core confidence-higher order construct. *Journal of Applied Psychology, 91*(6), 1208.

Verma, A., & Singh, A. (2009). *Leveraging webinar for student learning.* Paper presented at the 2009 International Workshop on Technology for Education.

Verma, A., & Singh, A. (2010). Webinar—Education through digital collaboration. *Journal of Emerging Technologies in Web Intelligence, 2*(2), 131-136.

Wiggins, G., Wiggins, G. P., & McTighe, J. (2005). *Understanding by design*: Ascd.

Zoller, U. (1990). Students' misunderstandings and misconceptions in college freshman chemistry (general and organic). *Journal of Research in Science Teaching, 27*(10), 1053-1065.

BIBLIOGRAPHY

Adelsman, H., & Whitely Binder, L. (2012). Ocean Acidifaction: From Knowledge to Action, Washington State's Strategic Response. *Washington State Blue Ribbon Panel on Ocean Acidification. Olympia, Washington Washington Department of Ecology*.

Ajzen, I. (1991). The theory of planned behavior. *Organizational behavior and human decision processes, 50*(2), 179-211.

Arnold, T., Mealey, C., Leahey, H., Miller, A. W., Hall-Spencer, J. M., Milazzo, M., & Maers, K. (2012). Ocean acidification and the loss of phenolic substances in marine plants. *PLoS one, 7*(4), e35107.

Auerbach, C., & Silverstein, L. B. (2003). *Qualitative data: An introduction to coding and analysis*: NYU press.

Avery, E. J. (2017). Public information officers' social media monitoring during the Zika virus crisis, a global health threat surrounded by public uncertainty. *Public Relations Review, 43*(3), 468-476.

Bandura, A. (1977). Self-efficacy: toward a unifying theory of behavioral change. *Psychological review, 84*(2), 191.

Bandura, A. (1997). *Self-efficacy: The exercise of control*: Macmillan.

Barton, A., Hales, B., Waldbusser, G. G., Langdon, C., & Feely, R. A. (2012). The Pacific oyster, Crassostrea gigas, shows negative correlation to naturally elevated carbon dioxide levels: Implications for near-term ocean acidification effects. *Limnology and oceanography, 57*(3), 698-710.

Barton, A., Waldbusser, G. G., Feely, R. A., Weisberg, S. B., Newton, J. A., Hales, B., . . . Jefferds, I. (2015). Impacts of coastal acidification on the Pacific Northwest shellfish industry and adaptation strategies implemented in response. *Oceanography, 28*(2), 146-159.

Birman, B. F., Desimone, L., Porter, A. C., & Garet, M. S. (2000). Designing professional development that works. *Educational leadership, 57*(8), 28-33.

Boehm, A. B., Jacobson, M. Z., O'Donnell, M. J., Sutula, M., Wakefield, W. W., Weisberg, S. B., & Whiteman, E. (2015). Ocean acidification science needs for natural resource managers of the North American west coast. *Oceanography, 28*(2), 170-181.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn* (Vol. 11): Washington, DC: National academy press.

Briñol, P., & DeMarree, K. (2012). *Social metacognition*: Psychology Press.

Bybee, R. W. (1990). Science for life & living: An elementary school science program from biological sciences curriculum study. *The American Biology Teacher, 52*(2), 92-98.

Bybee, R. W. (2002). *Learning science and the science of learning: Science educators' essay collection*: NSTA press.

Capstick, S. B., Pidgeon, N. F., Corner, A. J., Spence, E. M., & Pearson, P. N. (2016). Public understanding in Great Britain of ocean acidification. *Nature Climate Change, 6*(8), 763.

Cone, J., & Winters, K. (2013). Planning and evaluating science video programs using communication science. *Journal of Applied Communications, 97*(4), 9.

Cooley, S. R., Jewett, E. B., Reichert, J., Robbins, L., Shrestha, G., Wieczorek, D., & Weisberg, S. B. (2015). Getting ocean acidification on decision makers' to-do lists: dissecting the process through case studies. *Oceanography, 28*(2), 198-211.

Danielson, K. I., & Tanner, K. D. (2015). Investigating undergraduate science students' conceptions and misconceptions of ocean acidification. *CBE—Life Sciences Education, 14*(3), ar29.

Diamond, J., Horn, M., & Uttal, D. H. (2016). *Practical evaluation guide: Tools for museums and other informal educational settings*: Rowman & Littlefield.

Dickson, A. G., Sabine, C. L., & Christian, J. R. (2007). *Guide to best practices for ocean CO2 measurements*: North Pacific Marine Science Organization.

Dillman, D. A. (1978). *Mail and telephone surveys: The total design method* (Vol. 19): Wiley New York.

Doney, S. C., Balch, W. M., Fabry, V. J., & Feely, R. A. (2009). Ocean acidification: a critical emerging problem for the ocean sciences. *Oceanography, 22*(4), 16-25.

Driver, R., Asoko, H., Leach, J., Scott, P., & Mortimer, E. (1994). Constructing scientific knowledge in the classroom. *Educational researcher, 23*(7), 5-12.

Duran, L. B., & Duran, E. (2004). The 5E Instructional Model: A Learning Cycle Approach for Inquiry-Based Science Teaching. *Science Education Review, 3*(2), 49-58.

Enochs, L. G., & Riggs, I. M. (1990). Further development of an elementary science teaching efficacy belief instrument: A preservice elementary scale. *School science and mathematics, 90*(8), 694-706.

Erickson, B. D. (2018a). Effects of Teaching Household Actions to Address Ocean Acidification on Student Knowledge and Attitudes.

Erickson, B. D. (2018b). *Effects of Teaching Household Actions to Address Ocean Acidification on Student Knowledge and Attitudes.* (M.S. Thesis), Oregon State University, Corvallis, Oregon.

Fauville, G., Säljö, R., & Dupont, S. (2013). Impact of ocean acidification on marine ecosystems: educational challenges and innovations. *Marine Biology, 160*(8), 1863-1874.

Fazey, I., Bunse, L., Msika, J., Pinke, M., Preedy, K., Evely, A. C., . . . Reed, M. S. (2014). Evaluating knowledge exchange in interdisciplinary and multi-stakeholder research. *Global Environmental Change, 25*, 204-220.

Feely, R. A., Alin, S. R., Carter, B., Bednaršek, N., Hales, B., Chan, F., . . . Byrne, R. H. (2016). Chemical and biological impacts of ocean acidification along the west coast of North America. *Estuarine, Coastal and Shelf Science, 183*, 260-270.

Feely, R. A., Sabine, C. L., Lee, K., Berelson, W., Kleypas, J., Fabry, V. J., & Millero, F. J. (2004). Impact of anthropogenic CO2 on the CaCO3 system in the oceans. *Science, 305*(5682), 362-366.

Gattuso, J.-P., Mach, K. J., & Morgan, G. (2013). Ocean acidification and its impacts: an expert survey. *Climatic Change, 117*(4), 725-738.

Guskey, T. R., & Yoon, K. S. (2009). What works in professional development? *Phi delta kappan, 90*(7), 495-500.

Hales, B., Takahashi, T., & Bandstra, L. (2005). Atmospheric CO2 uptake by a coastal upwelling system. *Global biogeochemical cycles, 19*(1).

Harley, C. D., Randall Hughes, A., Hultgren, K. M., Miner, B. G., Sorte, C. J., Thornber, C. S., . . . Williams, S. L. (2006). The impacts of climate change in coastal marine systems. *Ecology letters, 9*(2), 228-241.

Herron, J. D. (1975). Piaget for chemists. Explaining what" good" students cannot understand. *Journal of Chemical Education, 52*(3), 146.

Imperial, M. T. (1999). Institutional analysis and ecosystem-based management: the institutional analysis and development framework. *Environmental management, 24*(4), 449-465.

Khourey-Bowers, C., & Fenk, C. (2009). Influence of constructivist professional development on chemistry content knowledge and scientific model development. *Journal of Science Teacher Education, 20*(5), 437-457.

Knobloch, N. A. (2003). Is experiential learning authentic? *Journal of Agricultural Education, 44*(4), 22-34.

Kocher, S. D., Toman, E., Trainor, S. F., Wright, V., Briggs, J. S., Goebel, C. P., . . . Steelman, T. A. (2012). How can we span the boundaries between wildland fire science and management in the United States? *Journal of Forestry, 110*(8), 421-428.

Kolb, A. Y., & Kolb, D. A. (2005). Learning styles and learning spaces: Enhancing experiential learning in higher education. *Academy of management learning & education, 4*(2), 193-212.

Kolb, D. A. (1984). Experience as the source of learning and development. *Upper Sadle River: Prentice Hall*.

Kolb, D. A. (2014). *Experiential learning: Experience as the source of learning and development*: FT press.

Lester, S. E., McLeod, K. L., Tallis, H., Ruckelshaus, M., Halpern, B. S., Levin, P. S., . . . Costello, C. (2010). Science in support of ecosystem-based management for the US West Coast and beyond. *Biological Conservation, 143*(3), 576-587.

Liu, X., Byrne, R. H., Lindemuth, M., Easley, R., & Mathis, J. T. (2015). An automated procedure for laboratory and shipboard spectrophotometric measurements of seawater alkalinity: Continuously monitored single-step acid additions. *Marine Chemistry, 174*, 141-146.

Loucks-Horsley, S. (1996). Principles of Effective Professional Development for Mathematics and Science Education: A Synthesis of Standards. *NISE brief, 1*(1), n1.

Mabardy, R. A., Waldbusser, G. G., Conway, F., & Olsen, C. S. (2015). Perception and response of the US west coast shellfish industry to ocean acidification: The voice of the canaries in the coal mine. *Journal of Shellfish Research, 34*(2), 565-573.

Maxwell, J. A. (2012). *Qualitative research design: An interactive approach* (Vol. 41): Sage publications.

Miles, M. B., Huberman, A. M., Huberman, M. A., & Huberman, M. (1994). *Qualitative data analysis: An expanded sourcebook*: sage.

Miller, J. J., Maher, M., Bohaboy, E., Friedman, C. S., & McElhany, P. (2016). Exposure to low pH reduces survival and delays development in early life stages of Dungeness crab (Cancer magister). *Marine Biology, 163*(5), 118.

Molenberghs, P., Trautwein, F.-M., Böckler, A., Singer, T., & Kanske, P. (2016). Neural correlates of metacognitive ability and of feeling confident: a large-scale fMRI study. *Social cognitive and affective neuroscience, 11*(12), 1942-1951.

Nakhleh, M. B. (1992). Why some students don't learn chemistry: Chemical misconceptions. *Journal of Chemical Education, 69*(3), 191.

Newmann, F. M. (1996). *Authentic achievement: Restructuring schools for intellectual quality*: Jossey-Bass.

Orr, J. C., Fabry, V. J., Aumont, O., Bopp, L., Doney, S. C., Feely, R. A., . . . Joos, F. (2005). Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature, 437*(7059), 681.

Pierrot, D., Lewis, D., & Wallace, D. (2006). CO2SYS. EXE—MS excel program developed for CO2 system calculations. ORNL/CDIAC-105a: Carbon dioxide Information center, Oak RidgeNational laboratory, US ….

Pressley, M., Borkowski, J. G., & Schneider, W. (2010). Cognitive strategies: Good strategy users coordinate metacognition and knowledge.

Roux, D. J., Rogers, K. H., Biggs, H., Ashton, P. J., & Sergeant, A. (2006). Bridging the science-management divide: Moving from unidirectional knowledge transfer to knowledge interfacing and sharing.

Ryan, C. M., & Cerveny, L. K. (2011). Wildland fire science for management: Federal fire manager information needs, sources, and uses. *Western Journal of Applied Forestry, 26*(3), 126-132.

Schneider, W., & Artelt, C. (2010). Metacognition and mathematics education. *ZDM, 42*(2), 149-161.

Sirhan, G. (2007). Learning difficulties in chemistry: An overview.

Stajkovic, A. D. (2006). Development of a core confidence-higher order construct. *Journal of Applied Psychology, 91*(6), 1208.

Townsend, M. S., Contento, I. R., Nitzke, S., McClelland, J. W., Keenan, D. P., & Brown, G. (2003). Using a theory-driven approach to design a professional development workshop. *Journal of nutrition education and behavior, 35*(6), 312-318.

Tschannen-Moran, M., & McMaster, P. (2009). Sources of self-efficacy: Four professional development formats and their relationship to self-efficacy and implementation of a new teaching strategy. *The elementary school journal, 110*(2), 228-245.

Vaske, J. J. (2008). *Survey research and analysis: Applications in parks, recreation and human dimensions*: Venture Pub.

Verma, A., & Singh, A. (2009). *Leveraging webinar for student learning.* Paper presented at the 2009 International Workshop on Technology for Education.

Verma, A., & Singh, A. (2010). Webinar—Education through digital collaboration. *Journal of Emerging Technologies in Web Intelligence, 2*(2), 131-136.

Volmert, A., Baran, M., Kendall-Taylor, N., Lindland, E., Haydon, A., Arvizu, S., & Bunten, A. (2013). Just the Earth doing its own thing": Mapping the gaps between expert and public understandings of oceans and climate change. *Washington, DC: FrameWorks Institute*.

Waldbusser, G. G., Hales, B., Langdon, C. J., Haley, B. A., Schrader, P., Brunner, E. L., . . . Gimenez, I. (2015). Saturation-state sensitivity of marine bivalve larvae to ocean acidification. *Nature Climate Change, 5*(3), 273.

Watson, G. R. (2006). Technology professional development: Long-term effects on teacher self-efficacy.

Wiggins, G., Wiggins, G. P., & McTighe, J. (2005). *Understanding by design*: Ascd.

Zoller, U. (1990). Students' misunderstandings and misconceptions in college freshman chemistry (general and organic). *Journal of Research in Science Teaching, 27*(10), 1053-1065.

APPENDICES

APPENDIX A: SURVEY

PRE-TRAINING QUESTIONNAIRE (t0)

Perceptions of OA understanding statements.

Please rate how much you agree or disagree with the following statements:

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree	Not applicable
	0 5 10	15 20 25	30 35 40	45 50 55	60 65 70	75 80 85	90 95 100	
1. I understand ocean acidification								☐
2. I understand marine carbonate chemistry								☐
3. I understand how to measure ocean acidification								☐
4. I understand how to measure carbonate system variables								☐
5. My colleagues/co-workers understand ocean acidification								☐
6. My colleagues/co-workers understand marine carbonate chemistry								☐
7. Ocean acidification issues are relevant to my job								☐
8. Learning more about marine carbonate chemistry will help me be more effective at my job								☐

If you would like to add source comments, qualifications, or other thoughts on the above questions, you may type them here before moving on:

____

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____

Perceptions of level of OA knowledge statements (taken from Gattuso et al., 2013).

Please report your level of knowledge for the following:

	No Knowledge	Limited Knowledge	Good Knowledge	Expert Knowledge
	0 5 10 15 20	25 30 35 40 45	50 55 60 65 70	75 80 85 90 95 100
9. Anthropogenic ocean acidification is caused by CO2 emissions to the atmosphere that end up in the ocean.				
10. Anthropogenic ocean acidification is currently in progress and is measurable.				
11. Anthropogenic ocean acidification that has occurred due to historical fossil fuel emissions will affect ocean chemistry for centuries.				
12. The rate of CO2 emissions is as important for determining ocean acidification impacts, as is the total magnitude of emissions.				
13. Human activities beyond CO2 emissions, such as eutrophication and runoff, affect ocean acidification in coastal regions.				
14. It is possible to define ocean acidity thresholds for some organisms, either globally or for some specific ecosystems or regions, that should not be exceeded.				

If you would like to add source comments, qualifications, or other thoughts on the above questions, you may type them here before moving on:

____

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Factual knowledge questions (⦿ indicates correct answer).

15. Where is the largest active reservoir of carbon on the planet found?

○ The atmosphere
⦿ The ocean
○ The lithosphere
○ Oil deposits
○ I don't know

16. What are the three carbon pumps of the ocean?

○ Biological, chemical, physical
○ Carbonate, bicarbonate, carbon dioxide
○ Inorganic, organic, biological
⦿ Carbonate, soft tissue, solubility
○ I don't know

17. Which of the following is most likely to benefit under ocean acidification conditions?

○ Oysters
○ Pteropods
⦿ Seagrasses
○ Corals
○ I don't know

18. A decrease in pH is a measure of what?

⦿ Increase in hydrogen ion [H^+] concentration
○ Decrease in hydrogen ion [H^+] concentration
○ Increase in hydroxide ion [OH^-] concentration
○ Decrease in carbonic acid ion [H_2CO_3] concentration
○ I don't know

19. The dissolved inorganic carbon (DIC) pool consists of which combination of the following?

○ Carbon monoxide, carbon dioxide, carbonate ion, carbonic acid
○ Carbon monoxide, carbon dioxide, carbonate ion, bicarbonate ion
⦿ Carbonic acid, carbon dioxide, carbonate ion, bicarbonate ion
○ Carbonic acid, carbon dioxide, bicarbonate ion, carbonite
○ I don't know

20. How many carbonate chemistry variables do we need in order to constrain the entire carbonate system?

○ One
⦿ Two
○ Three
○ Four
○ I don't know

21. What ancillary variables must be measured alongside carbonate system variables to characterize the entire carbonate system?

○ Salinity and total dissolved solids
○ Temperature and oxidation-reduction potential
○ Temperature and dissolved oxygen
⦿ Temperature and salinity
○ I don't know

22. Which of these carbonate system variables is not directly measurable?

○ Total alkalinity
⦿ Omega
○ pCO_2
○ TCO_2
○ I don't know

23. Which of the following does not impact alkalinity?

⦿ CO_2 gas exchange
○ Dissolution of $CaCO_3$
○ Precipitation of $CaCO_3$
○ Changes in salinity
○ I don't know

If you would like to add source comments, qualifications, or other thoughts on the above questions, you may type them here before moving on:

____
____
____

Demographic information.

What is the highest level of education you have received?

- Bachelor's
- Master's
- PhD

How much of your formal education focused on ocean acidification of marine carbonate chemistry?

- Entirely
- A lot
- Some
- A little
- None

How much professional experience would you say you have addressing ocean acidification issues?

- Entirely
- A lot
- Some
- A little
- None

The following question only displayed if respondents selected 'None' for the previous question.

How many years and/or months?
______ Years
______ Months

What kind of agency or organization do you work for?

- federal agency
- state agency
- university/college
- NGO
- industry
- other

POST-TRAINING QUESTIONNAIRE (t1)

Perceptions of OA understanding statements.

Please rate how much you agree or disagree with the following statements:

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree	Not applicable
	0 5 10	15 20 25	30 35 40	45 50 55	60 65 70	75 80 85	90 95 100	
1. I understand ocean acidification								☐
2. I understand marine carbonate chemistry								☐
3. I understand how to measure ocean acidification								☐
4. I understand how to measure carbonate system variables								☐
5. My colleagues/co-workers understand ocean acidification								☐
6. My colleagues/co-workers understand marine carbonate chemistry								☐
7. Ocean acidification issues are relevant to my job								☐
8. Learning more about marine carbonate chemistry will help me be more effective at my job								☐

If you would like to add source comments, qualifications, or other thoughts on the above questions, you may type them here before moving on:

____

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____

Perceptions of level of OA knowledge statements (taken from Gattuso et al., 2013).

Please report your level of knowledge for the following:

No Knowledge Limited Knowledge Good Knowledge Expert Knowledge

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100

9. Anthropogenic ocean acidification is caused by CO2 emissions to the atmosphere that end up in the ocean.
10. Anthropogenic ocean acidification is currently in progress and is measurable.
11. Anthropogenic ocean acidification that has occurred due to historical fossil fuel emissions will affect ocean chemistry for centuries.
12. The rate of CO2 emissions is as important for determining ocean acidification impacts, as is the total magnitude of emissions.
13. Human activities beyond CO2 emissions, such as eutrophication and runoff, affect ocean acidification in coastal regions.
14. It is possible to define ocean acidity thresholds for some organisms, either globally or for some specific ecosystems or regions, that should not be exceeded.

If you would like to add source comments, qualifications, or other thoughts on the above questions, you may type them here before moving on:

Factual knowledge questions (⦿ indicates correct answer).

15. Where is the largest active reservoir of carbon on the planet found?

- ○ The atmosphere
- ⦿ The ocean
- ○ The lithosphere
- ○ Oil deposits
- ○ I don't know

16. What are the three carbon pumps of the ocean?

- ○ Biological, chemical, physical
- ○ Carbonate, bicarbonate, carbon dioxide
- ○ Inorganic, organic, biological
- ⦿ Carbonate, soft tissue, solubility
- ○ I don't know

17. Which of the following is most likely to benefit under ocean acidification conditions?

- ○ Oysters
- ○ Pteropods
- ⦿ Seagrasses
- ○ Corals
- ○ I don't know

18. A decrease in pH is a measure of what?

- ⦿ Increase in hydrogen ion [H^+] concentration
- ○ Decrease in hydrogen ion [H^+] concentration
- ○ Increase in hydroxide ion [OH^-] concentration
- ○ Decrease in carbonic acid ion [H_2CO_3] concentration
- ○ I don't know

19. The dissolved inorganic carbon (DIC) pool consists of which combination of the following?

- ○ Carbon monoxide, carbon dioxide, carbonate ion, carbonic acid
- ○ Carbon monoxide, carbon dioxide, carbonate ion, bicarbonate ion
- ⦿ Carbonic acid, carbon dioxide, carbonate ion, bicarbonate ion
- ○ Carbonic acid, carbon dioxide, bicarbonate ion, carbonite
- ○ I don't know

20. How many carbonate chemistry variables do we need in order to constrain the entire carbonate system?

- ○ One
- ⦿ Two
- ○ Three
- ○ Four
- ○ I don't know

21. What ancillary variables must be measured alongside carbonate system variables to characterize the entire carbonate system?

- ○ Salinity and total dissolved solids
- ○ Temperature and oxidation-reduction potential
- ○ Temperature and dissolved oxygen
- ⦿ Temperature and salinity
- ○ I don't know

22. Which of these carbonate system variables is not directly measurable?

- ○ Total alkalinity
- ⦿ Omega
- ○ pCO_2
- ○ TCO_2
- ○ I don't know

23. Which of the following does not impact alkalinity?

- ⦿ CO_2 gas exchange
- ○ Dissolution of $CaCO_3$
- ○ Precipitation of $CaCO_3$
- ○ Changes in salinity
- ○ I don't know

If you would like to add source comments, qualifications, or other thoughts on the above questions, you may type them here before moving on:

____

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Webinar/lecture evaluation statements. Respondents indicated which webinars/lectures they attended and evaluated each separately using the following statements.

Please indicate which of the webinars/lectures you watched or were present for:

- O Biological Impacts
- O Carbon Cycle
- O marine Carbonate Chemistry
- O Principles of Measurement
- O None

Please rate how much you agree or disagree with the following statements. With regards to [LECTURE TITLE]:

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree	Not applicable
	0 5 10	15 20 25	30 35 40	45 50 55	60 65 70	75 80 85	90 95 100	
24. I learned a lot.								☐
25. It was interesting.								☐
26. It provided a good orientation to [TOPIC].								☐
27. It complemented my existing knowledge of [TOPIC].								☐
28. It complemented my existing knowledge of ocean acidification.								☐
29. It complemented my existing knowledge of marine carbonate chemistry.								☐
30. It was relevant to my job.								☐
31. Knowing this information will help me do my job better.								☐
32. I want to know more about this topic.								☐

33. If I needed more information about this topic, I feel I would know where to look for it.		☐
34. It was organized in an easy-to-understand way.		☐
35. It was too technical.		☐

In what ways might this information help you with your job?

If you would like to add source comments, qualifications, or other thoughts on the above questions, you may type them here before moving on:

In what ways do you think the webinars/broadcast lecture format helped or hindered your understanding of ocean acidification and the marine carbonate system?

If you would like to add source comments, qualifications, or other thoughts on the above questions, you may type them here before moving on:

Laboratory sessions and laboratory tasks evaluation statements.

Please rate how much you agree or disagree with the following statements. With regards to the lab sessions…:

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree	Not applicable
	0 5 10	15 20 25	30 35 40	45 50 55	60 65 70	75 80 85	90 95 100	
36. I learned a lot.								☐
37. They were interesting.								☐
38. Provided a good orientation to measuring carbonate system variables.								☐
39. Complemented my existing knowledge of ocean acidification.								☐
40. Complemented my existing knowledge of the marine carbonate system.								☐
41. Complemented my existing knowledge of how to measure marine carbonate system variables.								☐
42. Challenged me to apply the concepts I learned in the webinars/lectures.								☐
43. Were relevant to my job.								☐
44. Knowing this information will help me do my job better.								☐
45. Were organized in an easy-to-understand way.								☐
46. The content was too technical.								☐

In what ways might this information help you with your job?

____

____

____

Please rate how much you agree or disagree with the following statements. With regards to the tasks we conducted in lab…:

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree	Not applicable
	0 5 10	15 20 25	30 35 40	45 50 55	60 65 70	75 80 85	90 95 100	
47. The lab tasks were easy to do.								☐
48. I was capable of completing the lab tasks.								☐
49. Physically performing tasks in the lab helped me better understand ocean acidification.								☐
50. Physically performing tasks in the lab helped me better understand how to measure carbonate system variables.								☐
51. It was difficult to get accurate results.								☐
52. I believe with practice I could consistently get more accurate results.								☐
53. I could apply what I learned without significant additional training.								☐
54. I would like to know more about performing these tasks.								☐
55. If I needed more information, I feel I would know where to look for it.								☐
56. My educational background was relevant to helping me perform these tasks.								☐

57. Based on my professional experience, I felt well-prepared to perform these tasks.		☐
58. This work would be better suited for someone with a more relevant educational background or professional experience.		☐

Why do you think it was difficult to get accurate results?

In what ways has the scope of your educational background helped or hindered your ability to perform these tasks?

In what ways has the scope of your professional experience helped or hindered your ability to perform these tasks?

In what ways do you feel the lab sessions helped or hindered your understanding of the marine carbonate system?

If you would like to add source comments, qualifications, or other thoughts on the above questions, you may type them here before moving on:

Satisfaction statements.

Please rate how much you agree or disagree with the following statements:

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree	Not applicable
	0 5 10	15 20 25	30 35 40	45 50 55	60 65 70	75 80 85	90 95 100	
59. The facilities were appropriate.								☐
60. Information was communicated clearly.								☐
61. The field sample collection was useful.								☐
62. The webinars were useful.								☐
63. The lectures were useful.								☐
64. The lab sessions were useful.								☐
65. I learned a lot from the workshop.								☐
66. The workshop was worthwhile.								☐
67. I would recommend this workshop to my colleagues.								☐

Overall, how do you rate your experience with this workshop?

- O Poor
- O Fair
- O Average
- O Good
- O Excellent

Did you miss any significant portions of the workshop (e.g. final lab session on Thursday)?

- O Yes
- O No

What did you like best about the workshop?

____

____

____

What changes would you recommend to improve the course?

____

____

____

How do you see using this information or these skills going forward?

____

____

____

What did you like best about your instructors' teaching?

____

____

____

What would you change about your instructor's teaching?

____

____

____

Are there any other comments you would like to make?

____

____

____

FOLLOW-UP QUESTIONNAIRE (t2)

One of the outcomes we are evaluating from the OA workshop is whether and in what ways attending the course affects our participants' perceptions, thinking, and ultimately decision-making about measuring, monitoring, mitigating, and managing ocean acidification.

It is not always immediately obvious how our thinking, understanding, or actions may have responded to experiential learning, but for the following questions take a few moments to carefully consider how your experience in the workshop with either lecture material, laboratory activities, or even your peers, may have altered the way you think or feel about ocean acidification and marine carbonate chemistry.

Whether you perceive this change positively or negatively, consider how it may have shaped some of your thoughts, decisions, and even personal interactions, as a result.

Perceptions of OA understanding statements.

Please rate how much you agree or disagree with the following statements:

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree	Not applicable
	0 5 10	15 20 25	30 35 40	45 50 55	60 65 70	75 80 85	90 95 100	
1. I understand ocean acidification								☐
2. I understand marine carbonate chemistry								☐
3. I understand how to measure ocean acidification								☐
4. I understand how to measure carbonate system variables								☐
5. My colleagues/co-workers understand ocean acidification								☐
6. My colleagues/co-workers understand marine carbonate chemistry								☐
7. Ocean acidification issues are relevant to my job								☐
8. Learning more about marine carbonate chemistry will help me be more effective at my job								☐

If you would like to add source comments, qualifications, or other thoughts on the above questions, you may type them here before moving on:

____

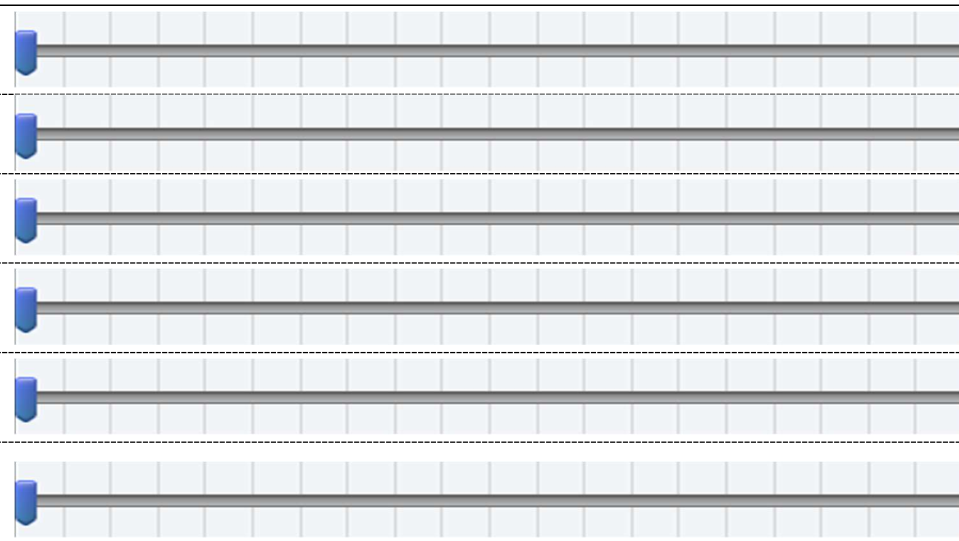
Perceptions of level of OA knowledge statements (taken from Gattuso et al., 2013).

Please report your level of knowledge for the following:

No Knowledge | Limited Knowledge | Good Knowledge | Expert Knowledge

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100

9. Anthropogenic ocean acidification is caused by CO2 emissions to the atmosphere that end up in the ocean.
10. Anthropogenic ocean acidification is currently in progress and is measurable.
11. Anthropogenic ocean acidification that has occurred due to historical fossil fuel emissions will affect ocean chemistry for centuries.
12. The rate of CO2 emissions is as important for determining ocean acidification impacts, as is the total magnitude of emissions.
13. Human activities beyond CO2 emissions, such as eutrophication and runoff, affect ocean acidification in coastal regions.
14. It is possible to define ocean acidity thresholds for some organisms, either globally or for some specific ecosystems or regions, that should not be exceeded.



If you would like to add source comments, qualifications, or other thoughts on the above questions, you may type them here before moving on:

Factual knowledge questions (⦿ indicates correct answer).

15. Where is the largest active reservoir of carbon on the planet found?

- ○ The atmosphere
- ⦿ The ocean
- ○ The lithosphere
- ○ Oil deposits
- ○ I don't know

16. What are the three carbon pumps of the ocean?

- ○ Biological, chemical, physical
- ○ Carbonate, bicarbonate, carbon dioxide
- ○ Inorganic, organic, biological
- ⦿ Carbonate, soft tissue, solubility
- ○ I don't know

17. Which of the following is most likely to benefit under ocean acidification conditions?

- ○ Oysters
- ○ Pteropods
- ⦿ Seagrasses
- ○ Corals
- ○ I don't know

18. A decrease in pH is a measure of what?

- ⦿ Increase in hydrogen ion [H^+] concentration
- ○ Decrease in hydrogen ion [H^+] concentration
- ○ Increase in hydroxide ion [OH^-] concentration
- ○ Decrease in carbonic acid ion [H_2CO_3] concentration
- ○ I don't know

19. The dissolved inorganic carbon (DIC) pool consists of which combination of the following?

- ○ Carbon monoxide, carbon dioxide, carbonate ion, carbonic acid
- ○ Carbon monoxide, carbon dioxide, carbonate ion, bicarbonate ion
- ⦿ Carbonic acid, carbon dioxide, carbonate ion, bicarbonate ion
- ○ Carbonic acid, carbon dioxide, bicarbonate ion, carbonite
- ○ I don't know

20. How many carbonate chemistry variables do we need in order to constrain the entire carbonate system?

- ○ One
- ⦿ Two
- ○ Three
- ○ Four
- ○ I don't know

21. What ancillary variables must be measured alongside carbonate system variables to characterize the entire carbonate system?

- ○ Salinity and total dissolved solids
- ○ Temperature and oxidation-reduction potential
- ○ Temperature and dissolved oxygen
- ⦿ Temperature and salinity
- ○ I don't know

22. Which of these carbonate system variables is not directly measurable?

- ○ Total alkalinity
- ⦿ Omega
- ○ pCO_2
- ○ TCO_2
- ○ I don't know

23. Which of the following does not impact alkalinity?

- ⦿ CO_2 gas exchange
- ○ Dissolution of $CaCO_3$
- ○ Precipitation of $CaCO_3$
- ○ Changes in salinity
- ○ I don't know

If you would like to add source comments, qualifications, or other thoughts on the above questions, you may type them here before moving on:

____

____

____

____

Learning needs statements.

As a direct result of participating in the workshop, please rate how much you agree or disagree with the following:

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree	Not applicable
	0 5 10	15 20 25	30 35 40	45 50 55	60 65 70	75 80 85	90 95 100	
24. I have utilized or referenced skills or information I learned from the workshop generally, in any context.								☐
25. I have encountered or identified gaps in my knowledge that I would not have previously recognized.								☐
26. I have independently read/researched additional information about OA in general.								☐
27. I have independently read/researched additional information about marine carbonate chemistry specifically.								☐
28. I am interested in additional learning/training opportunities regarding OA or marine carbonate chemistry.								☐
29. I feel I still need additional learning/training opportunities regarding OA or marine carbonate chemistry.								☐
30. I feel more confident in what I do know, as well as what I don't know, about OA or marine carbonate chemistry.								☐
31. If I were to seek out additional information about OA or marine carbonate chemistry, I would know where to look.								☐
32. I have adequate access to the additional information or resources I would need.								☐
33. The information or resources I have encountered are difficult to understand or interpret.								☐
34. If I encountered information that was difficult to understand or interpret, I would be able to figure it out.								☐

What, if anything, do you see as the missing piece(s) that would help solidify your learning about ocean acidification or marine carbonate chemistry?

____

____

____

What do you see as the next step in your learning about this?

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____

____

Interactions evaluation statements.

As a direct result of participating in the workshop, please rate how much you agree or disagree with the following:
I find I have been talking about ocean acidification…

	A lot less	Less	Somewhat less	About the same	Somewhat more	More	A lot more	Not applicable
	0 5 10	15 20 25	30 35 40	45 50 55	60 65 70	75 80 85	90 95 100	
35. in general								☐
36. with my colleagues or co-workers								☐
37. with my stakeholders and/or the public								☐

As a direct result of participating in the workshop, please rate how much you agree or disagree with the following:
I find I have been talking about marine carbonate chemistry, or measuring carbonate chemistry values…

	A lot less	Less	Somewhat less	About the same	Somewhat more	More	A lot more	Not applicable
	0 5 10	15 20 25	30 35 40	45 50 55	60 65 70	75 80 85	90 95 100	
38. in general								☐
39. with my colleagues or co-workers								☐
40. with my stakeholders and/or the public								☐

As a direct result of participating in the workshop, please rate how much you agree or disagree with the following:

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree	Not applicable
	0 5 10	15 20 25	30 35 40	45 50 55	60 65 70	75 80 85	90 95 100	
41. When I talk about OA generally, what I talk about or the way I talk about it is different.								☐
42. When I talk about marine carbonate chemistry, what I talk about or the way I talk about it is different.								☐
43. I have more confidence in my ability to explain OA to someone else.								☐
44. I have more confidence in my ability to explain how we measure marine carbonate chemistry values to someone else.								☐
45. I am more likely to show someone else how to work with relevant instrumentation or data.								☐

What did you learn in the workshop that has stuck with you the most?

___

___

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In what ways (if any) has the way you talk or think about ocean acidification changed as a result of attending the workshop?

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Decision-making statements.

As a direct result of participating in the workshop, please rate how much you agree or disagree with the following:

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree	Not applicable
	0 5 10	15 20 25	30 35 40	45 50 55	60 65 70	75 80 85	90 95 100	
46. I have a better idea of what resources or activities to focus on when it comes to my role in measuring, monitoring, mitigating, or managing OA.								☐
47. I have considered altering the scope, breadth, depth, or focus of some aspect of my work/project(s).								☐
48. I have thought about changing the way I do something at work based on information or skills I learned from the workshop.								☐
49. I have made a decision differently of changed the way I do something at work based on information or skills I learned from the workshop.								☐
50. I have considered changes to employee responsibilities or how to make staffing/hiring decisions differently.								☐
51. I would need to learn or understand more about OA or marine carbonate chemistry before making any changes.								☐

If you answered positively to any of the above questions, how would you classify these changes, with respect to addressing OA?

- ○ Measuring
- ○ Monitoring
- ○ Mitigating
- ○ Managing
- ○ Other
- ○ N/A

If you selected ‘Other’, please describe:

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What kinds of changes do you think are necessary in a position like yours to improve our ability to measure, monitor, mitigate, or manage OA?

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____

What, if any, kinds of barriers do you see to these changes?

____

____

____

Instrumentation and data statements.

As a direct result of participating in the workshop, please rate how much you agree or disagree with the following:

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree	Not applicable
	0 5 10	15 20 25	30 35 40	45 50 55	60 65 70	75 80 85	90 95 100	
52. I have more confidence in my understanding of how marine carbonate chemistry values are measured.								☐
53. I find myself thinking more about changing the way I work with instrumentation or data.								☐
54. I am making changes to the way I work with instrumentation or data.								☐
55. I find myself thinking more about acquiring new/different instrumentation.								☐
56. I am making real efforts to acquire new instrumentation.								☐
57. I find myself looking for more opportunities to train or help others with using instrumentation or data.								☐
58. I have changed my thinking about the need for certain kinds of instrumentation or data.								☐

What, if any, kinds of instrumentation, technology, or data would you ideally want to accomplish your goals related to OA or marine carbonate chemistry, and how would you use them?

___

___

___

Professional perspectives questions.

In my professional roles, I see myself able to contribute to OA issues via the following:

- ○ Measuring
- ○ Monitoring
- ○ Mitigating
- ○ Managing
- ○ Other
- ○ None of the above

If you selected 'Other', please describe:

____

____

____

In what ways would you personally or professionally like to contribute to measuring, monitoring, mitigating, or managing OA?

____

____

____

If you would like to add source comments, qualifications, or other thoughts on the above questions, you may type them here:

____

____

____

APPENDIX B: INTERVIEW QUESTIONS

Pre-interview Questions

1. Tell me about your work and what you do?

2. How would you/your colleagues like to better understand ocean acidification?
   a. In what ways would it be more relevant or useful to you?

3. How would you/your colleagues like to better understand the marine carbonate system?
   a. Is that something you talk about?
   b. In what ways would it be more relevant or useful to you?

4. What are you currently doing to measure ocean acidification?

5. When you're weighing the trade-offs for purchasing instruments and equipment for this kind of work, what are you top two priorities?
   a. What normally wins out – accuracy, precision, efficiency, cost, usability, availability, etc.?

Post-interview Questions

Conceptual Change Questions

1. What was the workshop experience like for you?

2. What do you feel you learned the most from the workshop?
    a. Was there anything you left feeling confused about?

3. Can you tell me about a time that you have used something you learned from the workshop?

4. In what ways do you think the workshop changed your thinking on OA?

5. As a result of the workshop, can you describe any moments when you have encountered gaps in your knowledge that might have previously gone unnoticed?

6. In what ways (if any) do you think the workshop helped your ability to talk about OA or marine carbonate chemistry?

7. Have you talked to others about the workshop, or about the things you learned in the workshop?
    a. Who did you talk to and what did you talk about?
    b. What motivated you to talk to them about it?

Self-efficacy/Empowerment to Action Questions

8. What did you learn in the workshop that you see as relevant or potentially relevant to your job? In what ways is it relevant?

9. In what ways do you think the workshop influenced your motivation to make changes in your approach to measuring, monitoring, mitigating, or managing OA issues?

10. Is there anything that you have done/are doing/plan to do differently now because of your experience in the workshop? [positive or negative] (e.g. talking about it more/differently, interpreting data/information differently, making different decisions, altering projects, purchasing equipment/instrumentation, changes to employee responsibilities, taught someone else what you learned, etc.)

11. What would you like to see done differently at your work with regards to measuring, monitoring, mitigating, or managing OA?
    a. How do you think you can contribute to this?
    b. Do you feel like if you did this it would make a difference? In what ways?
    c. How do you think your answers to these questions would have been different prior to the workshop?

12. What are some potential barriers to you accomplishing these things?
    a. In what ways do you feel your own level of knowledge/understanding are a barrier at this point? Is that something that could/should have been addressed by the workshop?
    b. How do you think your answers to these questions would have been different prior to the workshop?

Program Evaluation Questions

13. In what ways do you think working hands-on with instrumentation in the lab contributed to your learning?
    a. Do you think it was a necessary part of that learning?
    b. Do you think it was a necessary part of the workshop? (ie could you have gotten by without that component?)
    c. Is there something that would work better for you?

14. If you have worked with instrumentation to measure carbonate system values since the workshop, what problems have you experienced?

   a. What about using or interpreting data?
   b. What do think would help make it better?

15. The format of program was pre-webinars, followed by 2 days of hands-on training with a mix of lecture and lab time – how do you feel about this format?
    a. What worked/didn't work for you?
    b. What would you change?
    c. How do you feel about the length?
    d. How would you feel about a different format such as a series over weeks/months, a weeklong intensive course, more compact with an increased online component, etc?

APPENDIX C: WORKSHOP SCHEDULE

Table A.1 Training schedule followed during pilot workshop August 29th, 2018.

Day	Time	Activities	Duration	Learning Sequence	Goals	Notes
Wednesday	8:00 AM	**Discussion - Introduction**	20 mins	reflection	meet & greet	Go over agenda. Introductions: who each person is, what their background is, what they do, who they work for, why OA is relevant to their work
	8:20 AM	**Discussion - Concept Mapping**	20 mins	reflection abstract conceptualization	concept mapping activity	Work in pairs to build initial concept maps of OA/MCC, and how we might talk about/explain it to the public. Stimulate thinking about sticking points of understanding for the public as well as themselves.
	8:40 AM	**Discussion - Webinars 1 & 2 Reflection**	15 mins	reflection	refresh webinar info and get feedback	Webinars: what did they like? What would they change? (+/delta activity - instructors will write down for class to see) What's something new they learned? What questions do they still have? How would they summarize the main ideas?
	9:00 AM	**Lecture 1/Webinar 3 (broadcast)**	90 mins	conceptual introduction/exploration	overview of marine carbonate chemistry	content and depth will determine length here - probably benefit more from 90mins, but won't want to exceed that
	10:30 AM	break	15 mins		break	

10:45 AM	**Discussion - Intro to CO2SYS**	15 mins	**Start of Lab Session 1** conceptual introduction/exploration	orient to CO2SYS - following is to build conceptual understanding of marine carbonate system dynamics	Cover basic functions - input/outputs, conditions and scales, results; create Bjerrum-style plots of the distributions of carbonate species as a function of pH (may work in pairs)
11:00 AM	Lab - build graphs, answer challenges	10 mins	application	understand impact of temperature on pH	Challenge 1
11:10 AM	Lab - build graphs, answer challenges	10 mins	application	understand impact of salinity on pH	Challenge 2
11:20 AM	Lab - build graphs, answer challenges	10 mins	application	understand pH changes as driven by CO2 gas exchange	Challenge 3
11:30 AM	Lab - build graphs, answer challenges	15 mins	application	understand pH changes driven by precipitation/dissolution of calcite	Challenge 4
11:45 AM	Lab - wrap-up	15 mins	application	wrap-up, get feedback	wrap-up, review results, ask questions
12:00 PM	lunch	60 mins			
1:00 PM	**Lecture 2/Webinar 4 (broadcast)**	90 mins	conceptual introduction/exploration	measurement and constraining the carbonate system	help them better understand how to make decisions about measurement and analysis; pH measurement technology
2:30 PM	transition to lab room	10 mins		break	
2:40 PM	**Discussion - Discrete Sample Collection**	15 mins	**Start of Lab Session 2** conceptual introduction/exploration	intro to lab session; understand theory behind sample collection procedure	Explanation of laboratory procedures; instruct class on proper discrete sample collection procedure; ask questions about why discrete sample collection procedure will be conducted the way it is; ask questions about possible sources of error

2:55 PM	Lab - collect discrete samples	15 mins	application	discrete sample collection	Each group will come collect six discrete samples from flow-thru, until everyone has had an opportunity to collect a sample, and take back to their station
3:10 PM	Lab - pH calibration	15 mins	exploration & application	familiarization with calibration	Participants will calibrate pH meters
3:25 PM	Lab - discrete sample analysis	20 mins	exploration & application	measure pH and T of discrete samples	Challenge 1: each participant measures pH and T of each discrete sample, see how closely they can match advertised precision and accuracy of pH meters; groups log their own data and provide to instructors
3:45 PM	Lab - input measurements into CO2SYS	20 mins	exploration & application	calculate carbonate system variables	Input pH and T measurements into CO2SYS, along with S and other carbonate system variables provided to them (via BoL), and calculate carbonate system variables for their samples, as well as calculated pH, and compare results.
4:05 PM	Lab - discrete sample analysis	25 mins	exploration & application	measure pH and T of field samples	Participants may begin measuring pH and T of field samples
4:30 PM	**Discussion - Lab Session 2 Results**	30 mins	exploration & application	compile and analyze data	Comparison of BoL vs. iSAMI vs. pH meters - show results; why we see differences, how each pH meter compares; feedback about different pH meters and what participants think

					about their limitations, ease of use, functionality, etc
5:00 PM	break for day			break for day	

Table A.2 Training schedule followed during pilot workshop August 30th, 2018.

Day	Time	Activities	Duration	Learning Sequence	Goals	Notes
Thursday	8:00 AM	**Discussion - Day 1 Follow-Up**	20 mins	reflection & application	answer questions; work on concept maps	Review previous day - answer questions. Work on concept maps.
	8:20 AM	**Lecture - Measurement Methods**	40 mins	conceptual introduction/exploration	understand MCS measurement	Cover different ways to measure marine carbonate system variables and basics of BoL operation
	9:00 AM	**Discussion - TA Protocol**	30 mins	**Start of Lab Session 3** conceptual introduction/exploration	understand TA titration procedure	Explanation of laboratory procedures for the day; how to conduct TA titrations
	9:30 AM	Lab - collect discrete samples	10 mins	application	discrete sample collection	Each participant will come to bucket to collect discrete sample (several at once), until everyone has had an opportunity to collect a sample, and take back to their station
	9:50 AM	Lab - discrete sample analysis	20 mins	exploration & application	measure pH and T of discrete samples	Similar to previous day - participants take measurements and again attempt to match advertised precision/accuracy of pH meters and log their data.
	11:00 AM	Lab - TA measurement	10 mins	exploration & application	measure TA	First group member conducts TA titration on their discrete sample
	11:10 AM	Lab - TA measurement	10 mins	exploration & application	measure TA	Second group member conducts TA titration on their discrete sample
	11:20 AM	Lab - TA measurement	10 mins	exploration & application	measure TA	Third group member conducts TA titration on their discrete sample

11:30 AM	**Discussion - Lab Session 3 Results**	30 mins	exploration & application	compile and analyze data	Instructors guide discussion on comparison of BoL vs. iSAMI vs. participants' results on flow-through samples, why we see differences, how each pH meter compares, how their TA measurements compare, etc.
12:00 PM	lunch	60 mins			
1:00 PM	**Discussion - Operation of BoL and iSAMI**	30 mins	**Start of Lab Session 4** conceptual introduction	understand BoL and iSAMI operation	Instructors demonstrate basic operation of BoL and iSAMI
1:30 PM	Lab - groups attempt project challenges here	120 mins	exploration & application	project challenges	Groups will measure carbonate system variables on their field samples and characterize the carbonate system; they will have to coordinate among themselves for logistics, time, and use of instrumentation; if some people did not bring field samples, they can do the same tasks using flow-through water, or collect field samples during lunch or off-hours the previous day; groups will be instructed to log results and prepare a short presentation
3:30 PM	Lab - groups take turns explaining what their challenge was and how it went	60 mins	reflection	presentations	Groups present which variables they measured and how, how they rationalized their approaches, what their results were, why they got those results, and what they could have done differently
4:40 PM	**Discussion - Wrap-Up & Feedback**	30 mins	reflection	wrap-up, get feedback	Have participants share what they learned vs what didn't stick as well, what worked/didn't work, what they would change, etc.; Some or all of this time can be sacrificed if analysis/presentation time runs over.
5:00 PM	break for day			break for day	

APPENDIX D: DISCRETE WATER SAMPLE COLLECTION INSTRUCTIONS

Thank you for deciding to participate in our OA workshop pilot project. Your participation and feedback are crucial in shaping this research and future iterations of this educational program. As part of the workshop, we are asking each of our participants to collect and bring some discrete field samples to the lab for analysis. This task should be fairly minimal – about 10 minutes total for preparation and sample collection. Please choose a natural water source of your interest, ideally one that your work typically focuses on and that is marine or has a marine influence, and then collect 6 discrete samples following the instructions below. Included in this kit are some of the materials you need, although you will need to provide a few things as well. Once you have collected your samples, put them on a shelf until it is time to bring them to the workshop on August 29th-30th. See you then!

INSTRUCTIONS FOR DISCRETE WATER SAMPLE COLLECTION FOR CARBONATE SYSTEM ANALYSIS

Materials provided:

- ~5mL of saturated mercury(II) chloride ($HgCl_2$) – CAUTION: HIGHLY TOXIC!
- 1 red bottle capper
- 8 bottle caps
- 3 disposable pipets

Additional materials you will need:

- pH meter (any kind will do)
- digital thermometer (if your pH meter doesn't have one)
- 6 empty amber beer bottles (NOT twist-offs)
- tape for labeling bottles
- Sharpie marker

- Pencil/paper or something to log your data (don't forget to bring this with you to lab!)

Preparation:

1. Wash beer bottles with soap and water, then thoroughly rinse for 30 seconds *at least* 3x with deionized (DI) water, and set to dry.
2. Once dry, label each bottle with tape or suitable label, and write the following: Name, Location, Date, Time, pH, Temp.

Sample Collection:

3. Once on site, pre-condition (i.e. rinse) each bottle 3x with several mLs of your intended sample water.
4. Submerge each bottle to fill it <u>to the brim</u> with sample. If sampling from a pipe or hose, allow each bottle to overfill at least half of its volume.
5. Using a disposable pipet, remove ~1% of the sample volume (~2.5-3mLs).
6. Add 2-4 drops of saturated $HgCl_2$ (you may want to wear nitrile gloves).
7. Place a bottle cap on the capper magnet, cap the bottle, and invert 3x to mix.
8. Measure pH and temperature (Celsius) of sample water, and label on bottle with date and time.
9. Record make/model of pH meter (and thermometer if used).
10. Bottles may be stored at room temperature until time of analysis.

Don't forget to bring your samples and their metadata to the workshop, and a laptop if you have one. See you then!

APPENDIX E: LABORATORY SETUPS AND PROCEDURES

LAB SESSION 1

Objectives:

- Understand how to use a carbonate system calculator to constrain the marine carbonate system
- Understand the relationships and dynamics of the parameters of the carbonate system
- Understand the different pH scales and their impact on pH

Materials:

- Computers with CO2SYS installed (or other carbonate system calculator)

Setup:

- Only computers; room setup should accommodate students working in pairs or small groups

Procedures:

1. Instructor will provide students an overview of how to operate and manipulate CO2SYS spreadsheet.
2. Students will be allowed approximately one hour to explore CO2SYS operation and complete a series of challenges (see APPENDIX F: CARBONATE CALCULATION LAB CHALLENGES USING CO2SYS).
3. Instructors will answer questions and assist students throughout this process.
4. Towards end of lab period, students will be asked to orally present their findings for each challenge/question
    a. As a class, go through each challenge briefly. Ask: what did you find?
5. Instructors will gather feedback about what students found difficult or didn't understand.
6. Additional questions/challenges (if need be):
    a. How sensitive is pH to changes in T and S?
    b. What happens to CO_3 and HCO_3 as pCO_2 increases?

c. For every unit increase in TCO_2, how much increase will we see in TA? Why?
d. At what pH do we see a shift from $[CO_2^*]$ dominating to CO_3?
e. At what pCO_2 values do we see the respective Ω_{arag} and Ω_{calc} equal to 1?

Lab Session 2

Objectives:

- Learn proper pH probe calibration and measurement technique
- Experience real-world marine carbonate system measurement and calculation
- Understand differences in precision and accuracy between different choices in instrumentation, and resultant differences in carbonate system calculations

Materials:

- Acid-washed crown-cap amber beer bottles
- Pickling kit supplies (see APPENDIX D: DISCRETE WATER SAMPLE COLLECTION INSTRUCTIONS)
- CO_2 analyzer (connected to seawater flow-thru system)
- pH probes (different types – see below) with integrated temperature probes, and manufacturer instructions or standard protocol included
- Two or more NIST-certified or NIST-traceable pH buffer solutions (for calibration)
- Beakers
    - 1x 100mL for each buffer per station
    - 1x 500mL per station for rinsing pH probes
    - 1x 250mL per person for discrete sample collection
- DI water in wash bottles or with disposable pipets for rinsing
- Computers with CO2SYS installed or other carbonate system calculator
- Chemical waste container

Setup:

- In lab:
    - Beer bottles
    - Pickling kit
    - CO_2 analyzer and/or other precision instrumentation to measure carbonate system parameters
- At each station:
    - 1x pH probe

- Beakers
- DI water
- computers

Procedure:

1. Participants are initially staged at each pH probe station.
2. Instructors explain lab session and sample collection procedures, and lead brief guided discussion focusing on why sample collection will be conducted the way it is.
3. Class is instructed on standard procedure for collecting discrete samples. Further discussion may cover potential sources of error, and other problems or considerations.
4. Class will be instructed on proper handling of pH probes (e.g. rinsing technique).
5. Participants will work in groups of 2-4 to get through as many tasks as they can.
6. Any live-seawater sampling equipment should be turned on and left to continuously sample during the lab session.
7. Participants collect six discrete samples in beer bottles the flow-thru and preserve them for analysis. If participants collected independent field samples, they may use those instead.
8. Participants will record the time each sample is collected as well as T, S, and two carbonate system parameters from CO_2 analyzer (preferably pCO_2 or TCO_2) or other precision instrumentation.
9. Groups will calibrate pH meters before each sampling turn using the buffers provided (they may begin this process while others are collecting discrete samples).
   a. They should calibrate meters following instructions included with each pH meter,
   b. followed by pre-calibration curve checks on buffers (record pH and T, use a spreadsheet to generate a curve if not provided with one).

10. Participants are challenged to see if they can replicate the advertised accuracy and precision of their respective pH meters. Results between meters will be compared at end of lab.
11. They will be provided with T, S, and pCO_2 or TCO_2 for their sample from the CO_2 analyzer, and asked to calculate pH and other carbonate system values (using CO2SYS), for comparison.
12. As time allows, groups will rotate stations measuring pH and T on their respective discrete samples, calibrating each meter before and after their measurements.
13. Toward end of lab period, results from each group are collected as well as continuous sampling data from precision instrumentation and compared. Instructors lead a brief guided discussion focusing on how participant results compare to CO_2 analyzer and other instruments, and how their carbonate system calculations compare to one another.
14. Additional discussion may include questions about different factors they think may be affecting their readings (e.g. calibration procedures, gas exchange, changes in temperature, dilution from mercuric chloride and/or residual DI water on probes, time of collection, salinity, etc.).
15. Instructors may prompt participants about the next lab session, and ways in which we might we begin to constrain the carbonate system and make those measurements.
16. As time permits, instructors will ask questions and get feedback about different pH meters and what participants think about their limitations, ease of use, functionality, etc.

Lab Session 3

Objectives:

- Practice pH measurement skills learned in previous lab
- Learn basic method to measure total alkalinity (TA)
- Become familiar with how to use advanced precision instrumentation

Materials:

- All materials from Lab Session 2
- Single-point alkalinity titrations:
  - Tank of pre-pure N_2 gas with regulator and small diameter (<5mm) tubing
  - 0.25N HCl
  - 1.0mL micropipettor with tips

Setup:

- Same setup as Lab Session 2
- Station with N_2 tank, micropipettor, and HCl

Procedure:

1. Participants are given opportunity to further constrain carbonate system with TA titrations and other carbonate system measurements from CO_2 analyzer or other precision equipment (following morning instruction).
2. Class is instructed on procedure for measuring TA using single-point titration method (see APPENDIX G: ALKALINITY TITRATION PROCEDURE).
3. Similar to Lab Session 2, participants will again collect discrete seawater samples from flow-thru seawater lines, again measuring pH, followed by the TA procedure.
4. Participants will work in groups of 2-4 to get through as many tasks as they can.
5. Any live-seawater sampling equipment should be turned on and left to continuously sample during the lab session.
6. Participants collect six discrete samples in beer bottles the flow-thru and preserve them for analysis. If participants collected independent field samples, they may use those instead.

7. Groups will be assigned different combinations of two carbonate system measurements and will take as many replicates as possible using different pH meters. Due to the limitation of the single N_2 tank setup, groups will take turns being guided on using the CO_2 analyzer to acquire one measurement of either pCO_2 or TCO_2 for their carbonate system calculations (or they may use other equipment as time and interest allow). Once every group has analyzed at least one discrete sample on the CO_2 analyzer, they may begin analyzing a second sample for a second variable (e.g. if they measured pCO_2 the first time, they should use TCO_2 the second time).
8. Groups will calibrate pH meters before each sampling turn using the buffers provided (they may begin this process while others are collecting discrete samples).
    a. They should calibrate meters following instructions included with each pH meter,
    b. followed by pre-calibration curve checks on buffers (record pH and T, use a spreadsheet to generate a curve if not provided with one).
9. They will measure and record pH and T of their discrete samples.
10. They will titrate discrete samples to determine TA.
11. Groups will then enter data into CO2SYS to calculate carbonate system using their pH, TA and/or pCO_2 and TCO_2 measurements.
12. Toward end of lab period, results from each group are collected as well as continuous sampling data from precision instrumentation and compared. Instructors lead a brief guided discussion focusing on how and why measurements may have changed over time, how their results compare to the CO_2 analyzer or other instrumentation, and how their carbonate system calculations compare to one another.
13. Additional discussion may include questions about different factors they think may be affecting their results.

Lab Session 4

Objectives:

- Participants practice TA titration skills learned in previous lab
- Participants practice using advanced precision instrumentation
- Further explore constraining carbonate system with different methods and its impact on results

Materials:

- Same as previous lab sessions

Setup:

- Same as previous lab sessions
- Groups are free to take measurements of carbonate system variables using instruments and methods of their choice

Procedure:

1. Participants who wish to use CO_2 analyzer during lab can then be guided on its operation to obtain their measurements.
2. Similar to Lab Session 3, participants are challenged to constrain the carbonate system on discrete samples using two measurable carbonate system parameters of their choice, given the available methods. This will give them an opportunity to become more familiar with operating instrumentation, as well as practice the methods from previous lab sessions.
3. Participants are instructed to log and analyze data and prepare short (<5 min) informal presentation on their findings. Groups may prepare short PowerPoint presentations (<5 slides) to exhibit data.
4. At the end of lab, groups present their results, informing the class of 1) location of sample collection (if collected independently) 2) parameters analyzed 3) methods used to analyze samples 4) what factors and sources of error may have influenced accuracy of their results, and 5) what they would do differently in the future.
5. As time allows, instructors may lead brief guided discussion about general workshop feedback.

WET-LAB PH SENSOR SUPPLIES LIST

The wet-lab sessions described above relied on a setup of seven stations with a variety of off-the-shelf hand-held pH sensors for participants to measure pH and temperature. The sensors were chosen not only to familiarize participants with their operation, but also the available range of accuracy and precision, and available measurement technologies (i.e. ion-selective glass bulb electrode vs. ion-sensitive field-effect transistors or ISFET). The objective was to equip participants with the skills to properly utilize these instruments, and be able to appropriately interpret the accuracy, precision, and reliability of their measurements. As time and laboratory space allow, participants should be encouraged to try different pH sensors for each session, to increase their exposure to and familiarity with these tools.

Table A.3 List of pH sensors, probes, and buffers used for wet-laboratory sessions.

Type	Brand	Model/Item #	Price	Qty	Description/Notes
ISFET	DeltaTrak	24006	$ 219.00	1	accuracy 0.1, resolution 0.1; w/temp
ISFET	DeltaTrak	24310	$ 760.00	1	accuracy 0.01, resolution 0.01; w/temp; handheld
ISFET	DeltaTrak	24311	$ 450.00	1	probe for above
ISFET	Sentron	S1600	$ 1,395.00	1	accuracy 0.005, resolution 0.005; probe separate
ISFET	Sentron	ConeFET probe	$ 550.00	1	probe for use with either of the above; includes temp
bulb	Hanna	HI98107	$ 39.50	1	resolution/accuracy 0.1
bulb	Oakton	pHTestr® 30	$ 111.16	1	accuracy 0.01; w/temp probe
bulb	Oakton	pH 150	$ 401.20	1	accuracy/precision 0.01; w/temp; handheld; mV offset
bulb	Hach	HQ11D	$ 810.00	1	resolution 0.001; w/temp & salinity; handheld w/probe
buffer	Ricca	R1500000-4A	$ 60.22	1	4L, colorless, pH 4, NIST-traceable
buffer	Ricca	R1550000-4A	$ 58.37	1	4L, colorless, pH 7, NIST-traceable
buffer	Ricca	R1600000-4A	$ 59.17	1	4L, colorless, pH 10, NIST-traceable

APPENDIX F: CARBONATE CALCULATION LAB CHALLENGES USING CO2SYS

Using CO2SYS

We will examine how the carbonate system responds to change and how it varies in the ocean. Since we cannot measure all of the components of the carbonate system (e.g. HCO_3^- CO_3^{2-}) we can use thermodynamic equilibrium relationships to calculate the entire system if we have two of the variables measured. However, the quality of the calculations depends on the measurements you have to make the calculations with.

You will have to pick a number of constants and constraints on the system calculations. Initially you should use the following:

Set of Constants: K1, K2 from Mehrbach et al. 1973, Refit by Dickson and Millero 1987
$KHSO_4$: Dickson
pH Scale: Total
$[B]_I$ Value: Upstrom 1974

Enter the data you have under the red header labeled "START". You may only enter 2 variables in the "DATA" section (if more than 2, it will choose the first two starting from the left). Click on the "Clear DATA" or "Clear Results" buttons as needed. Once everything is set click on the "START" banner.

Note: "input conditions" are the conditions during analysis. For shipboard analyses the input pressure would be 0 and the input temperature would be the temperature of analysis. The output conditions are the temperature and pressure at which you wish to calculate the parameters. For instance, if you measure the pH at 25 ˚C and wish to determine the pH at depth and temperature at which the sample was obtained, you would list 0 and 25 as input P (dbars) and t (˚C) and insert *in situ* P (dbars) and t (˚C) as output.

In-class Challenges

1. Calculate carbonate system species for S = 35, T = 15 ˚C, and pH = 8.2, in equilibrium with historic atmospheric *p*CO2 concentrations (@280 ppm).
    a. What is the TCO_2 for this solution?
    b. What are the saturation states for calcite and aragonite?
    c. Now decrease pH to 8.1 and increase pCO_2 to current atmospheric concentrations (http://co2now.org). How do these values change? Why?

2. How will rampant CO_2 production over the next century affect the surface ocean? Pre-industrial values of pCO_2 were around 280 ppm. Some projections anticipate a tripling of this value to ~850 ppm by the year 2100. Assume S = 35, T = 15 ˚C, and alkalinity stays constant at 2200 µmol/kg. What might the surface ocean pH have been like in pre-industrial times?
    a. Currently, atmospheric pCO_2 is ~410 ppm – what should the pH look like right now? What will the pCO_2 be at when the pH drops below 8.0?
    b. What will the pH be when pCO_2 reaches 850 ppm?

3. For the previous problem, plot changes in Ω_{arag} and Ω_{calc}.
    a. Which one is decreasing at a faster rate?
    b. Which one will become undersaturated first?

4. How is pH on the Total and NBS scales impacted by changes in salinity?
    a. Assume T = 25 ˚C, TCO_2 = 2100 µmol/kg, pCO_2 = 410 ppm, and vary the salinity from 0 to 40. Calculate the difference between the two scales and plot over salinity space. Add a trendline and its equation (second-order polynomial).
    b. What is the pH difference at S = 0?
    c. At S = 35?
    d. Are the differences in pH between the two scales meaningful in terms of ocean acidification?

APPENDIX G: ALKALINITY TITRATION PROCEDURE

Protocol for single-point titration of alkalinity.

Titration procedure*:

1. Weigh a clean, dry beaker on a balance and record the mass.

2. Rinse the inside of the beaker 3x with sample seawater.

3. Add ~100 mL of sample seawater.

4. Re-weigh the beaker containing your seawater sample and subtract the mass of the empty beaker to determine the mass (M_{SW}) of your sample.
    a. Make sure the balance and outside of the beaker are dry prior to this step.

5. Using a calibrated micropipette, carefully add 1.0 mL of 0.25 N HCl solution to your seawater sample to convert the dissolved inorganic carbon in the sample to aqueous CO_2.

6. Gently swirl the beaker to thoroughly mix the acid, being careful not to splash any sample onto the sides of the beaker. Alternatively, mix on a stir plate.

7. Insert the end of a tube from a tank of CO_2-free compressed gas (pre-pure N_2 or ultra-pure air) to the bottom of the beaker and purge the sample of aqueous CO_2 by gently bubbling for 5 minutes, being careful not to splash sample onto the sides of the beaker.

8. Using a calibrated pH meter, determine the pH of your sample, and apply necessary corrections.

9. Determine the total alkalinity of your sample (µmol/kg) using the following equation:

$$A_T = \{[HCl]_A M_A - [H^+]_{ASW} M_{ASW}\}/M_{SW}$$

where $[HCl]_A$ = the concentration of the HCl added to the sample, M_A = the mass (or volume) of the acid added to the sample, $[H^+]_{ASW}$ = the excess hydrogen ion concentration in the acidified CO_2-free seawater which is determined using $pH = -log[H^+]_{ASW}$ corrected to the pH Total Scale (~pH_{tot} = pH_{NBS}-0.13 for most marine salinities), M_{SW} = the mass (or volume) of the seawater sample, and M_{ASW} = the mass (or volume) of M_A + M_{SW}. If prepared volumetrically, the mass terms may be converted to volume terms using appropriate densities. The density of seawater is salinity dependent and should be referenced from a table or online calculator.

*This procedure is intended to be accomplished relatively quickly after sample collection, to avoid changes in temperature of the seawater sample. If temperature changes of >10°C are anticipated from start to finish, temperature corrections must be applied (Liu et al., 2015).

Reference: Liu, X., Byrne, R. H., Lindemuth, M., Easley, R., & Mathis, J. T. (2015). An automated procedure for laboratory and shipboard spectrophotometric measurements of seawater alkalinity: Continuously monitored single-step acid additions. Marine Chemistry, 174, 141-146.

APPENDIX H: BROAD OA KNOWLEDGE QUESTIONS RESULTS: COMPARISON TO GATTUSO ET AL. (2013)

Six declarative statements taken from (Gattuso et al., 2013) were used to assess participants' understanding of OA in a global context, and the mechanisms driving it. Respondents were asked to report their level of knowledge with regards to these six general knowledge statements, on a 1-100 Likert-type slider scale with four ordered responses from "No Knowledge" to "Expert Knowledge", respectively (see APPENDIX A: SURVEY). For comparison to results from Gattuso et al., our baseline (incoming) scale responses were consolidated according to those reporting 'Good' or 'Expert' knowledge (51-100) and those reporting 'No' or 'Limited' knowledge (1-50). Gattuso et al. only assessed knowledge among OA 'experts', which were partially classified according to level of education (i.e. possessing a PhD), and results from our respondents who possess a PhD have been provided separately for additional comparison (Table A.4).

Overall, our respondents rated their level of knowledge similarly for all six statements, on average providing ratings in the range of 'Good Knowledge' (50-75). Those who possess a PhD tended to rate their level of knowledge higher than the population as a whole, by an average of five points. In both cases, the proportion who rated themselves as having 'Good' or 'Expert' knowledge tended to be higher than that of the respondents from Gattuso et al., by 11 points on average overall, and 17 points for those with PhDs.

Responses to these broad OA knowledge statements were tracked over time by the post-training (t1) and follow-up (t2) questionnaires for the professional marine resource managers who participated in the hands-on training program (Table A.5). However, because the training focused on details of the marine carbonate system, we did not anticipate observing significant changes over time due to the more generalized nature of these statements. Initial response ratings from those who attended the training tended to be slightly lower than the larger baseline population of marine resource managers but increased over time and exceeded overall baseline results at t2. Results of Wilcoxon signed rank tests reveal no significant differences over time with the exception of S14, which increased significantly from t0-t1 (p = .021).

Table A.4 Incoming broad OA knowledge comparisons.
Baseline perceptions of self-reported broad OA knowledge for all pre-training respondents (*n* = 28) and PhD group separately (*n* = 11), compared to results from Gattuso et al. (2013).

	Mean ratings and standard deviations (PhD only)[1]		Proportion of respondents reporting good or expert knowledge		Proportion of respondents reporting limited or no knowledge	
	$\bar{x}$	S.D.	Overall (PhD)	Gattuso et al.	Overall (PhD)	Gattuso et al.
9.Anthropogenic ocean acidification is caused by CO2 emissions to the atmosphere that end up in the ocean	75 (77)	19 (18)	.86 (.82)	.77	.14 (.18)	.23
10.Anthropogenic ocean acidification is currently in progress and is measurable	73 (77)	22 (19)	.86 (.82)	.70	.14 (.18)	.30
11.Anthropogenic ocean acidification that has occurred due to historical fossil fuel emissions will affect ocean chemistry for centuries	72 (80)	23 (16)	.79 (.91)	.61	.21 (.09)	.39
12.The rate of CO2 emissions is as important for determining ocean acidification impacts, as is the total magnitude of emissions.	61 (66)	27 (32)	.61 (.73)	.66	.39 (.27)	.34
13.Human activities beyond CO2 emissions, such as eutrophication and runoff, affect ocean acidification in coastal regions.	73 (78)	22 (24)	.79 (.82)	.57	.21 (.18)	.43
14.It is possible to define carbonate system thresholds for some organisms, either globally or for some specific ecosystems or regions, that should not be exceeded.	63 (69)	28 (27)	.68 (.82)	.60	.32 (.18)	.40
Overall (mean)	69 (74)	23 (23)	.76 (.82)	.65	.24 (.18)	.35

[1] Mean user ratings responses on 100-point scale from 1 "No Knowledge" to 100 "Expert Knowledge."

Results of the post-training and follow-up questionnaires point to a potential positive impact of the training on participant perceptions of their own level of knowledge regarding OA. Simultaneously, their perceptions of their understanding of OA also increased slightly, while understanding of MCC relaxed slightly, suggesting that while specific details may be forgotten, experiencing the training program positively impacted perceptions of understanding and level of knowledge of OA overall. The significant response rating increase observed for S14 from t0-t1 may have occurred as a result of repeated lecture themes and discussion which did at times briefly emphasize the ability to define organism sensitivity thresholds for the carbonate system.

Table A.5 Broad OA knowledge change.
Perceptions of broad OA knowledge comparisons pre-training (t0), post-training (t1), and follow-up (t2) results of Wilcoxon signed-rank test (n = 15)

	Self-assessed level of OA knowledge[1]			*p*-value[2]		
	t0	t1	t2	t0-t1	t0-t2	t1-t2
9. Anthropogenic ocean acidification is caused by CO2 emissions to the atmosphere that end up in the ocean	73	76	78	.610	.712	.955
10. Anthropogenic ocean acidification is currently in progress and is measurable	72	74	79	.865	.513	.551
11. Anthropogenic ocean acidification that has occurred due to historical fossil fuel emissions will affect ocean chemistry for centuries	71	76	78	.638	.551	.932
12. The rate of CO2 emissions is as important for determining ocean acidification impacts, as is the total magnitude of emissions.	56	69	71	.125	.191	1.000
13. Human activities beyond CO2 emissions, such as eutrophication and runoff, affect ocean acidification in coastal regions.	69	77	74	.168	.509	.396
14. It is possible to define carbonate system thresholds for some organisms, either globally or for some specific ecosystems or regions, that should not be exceeded.	61	76	68	.021	.753	.394

[1] Mean user ratings responses on 100-point scale from 1 "No Knowledge" to 100 "Expert Knowledge."

Differences between our results and Gattuso et al. (2013) may be attributed to differences in educational and professional backgrounds of the two sample populations. The respondents featured in Gattuso et al. were all research scientists active in the field of OA research, whereas our respondents hold professional roles in management and applied sciences and are likely to represent a greater diversity of scientific disciplines in their professional and educational backgrounds. Approximately 39% of our overall study respondents possess PhDs, compared to approximately 27% of our training participants, and 100% of those surveyed by Gattuso et al.

APPENDIX I: OTHER RESULTS

The following tables summarize scale results from the post-training (t1) and follow-up (t2) questionnaires.

Table A.6 Lecture review results.
Participant responses to statements evaluating webinars and in-person lectures.[1]

	Average rating of statement agreement and standard deviation[2]			
	W1 *n* = 10	W2 *n* = 10	L1 *n* = 14	L2 *n* = 14
24. I learned a lot.	66 (30)	79 (18)	76 (26)	81 (22)
25. It was interesting.	72 (30)	78 (16)	76 (27)	79 (27)
26. It provided a good orientation to [TOPIC].	69 (32)	80 (14)	73 (26)	85 (11)
27. It complemented my existing knowledge of [TOPIC].	72 (23)	77 (16)	71 (28)	81 (20)
28. It complemented my existing knowledge of ocean acidification.	73 (27)	49 (25)	72 (27)	77 (17)
29. It complemented my existing knowledge of marine carbonate chemistry.	61 (31)	74 (21)	81 (13)	76 (21)
30. It was relevant to my job.	68 (31)	70 (22)	67 (26)	71 (23)
31. Knowing this information will help me do my job better.	67 (32)	73 (18)	66 (27)	68 (26)
32. I want to know more about this topic.	74 (30)	76 (8)	73 (25)	70 (22)
33. If I needed more information about this topic, I feel I would know where to look for it.	63 (25)	72 (21)	72 (19)	70 (22)
34. It was organized in an easy-to-understand way.	61 (26)	73 (14)	66 (26)	73 (21)
35. It was too technical.	39 (26)	49 (26)	53 (25)	44 (26)

[1] W1 = ‘Biological Impacts of OA’, W2 = ‘The Carbon Cycle’, L1 = ‘Marine Carbonate Chemistry’, L2 = ‘Measurement’.
[2] Mean response ratings on 100-point scale from 1 “strongly disagree” to 100 “strongly agree.”

Table A.7 Laboratory session review results.
Participant responses to statements evaluating laboratory sessions (n = 16).

	Average rating of statement agreement and standard deviation[2]	
	$\bar{x}$	S.D.
36. I learned a lot.	77	21
37. They were interesting.	74	21
38. Provided a good orientation to measuring carbonate system variables.	78	19
39. Complemented my existing knowledge of ocean acidification.	77	20
40. Complemented my existing knowledge of the marine carbonate system.	79	20
41. Complemented my existing knowledge of how to measure marine carbonate system variables.	80	21
42. Challenged me to apply the concepts I learned in the webinars/lectures.	75	26
43. Were relevant to my job.	61	32
44. Knowing this information will help me do my job better.	66	28
45. Were organized in an easy-to-understand way.	65	28
46. The content was too technical.	40	23

[1] Mean response ratings on 100-point scale from 1 "strongly disagree" to 100 "strongly agree."

Table A.8 Laboratory task review results.
Participant responses to statements evaluating laboratory tasks (n = 16).

	Average rating of statement agreement and standard deviation[2]	
	$\bar{x}$	S.D.
47. The lab tasks were easy to do.	80	12
48. I was capable of completing the lab tasks.	87	11
49. Physically performing tasks in the lab helped me better understand ocean acidification.	72	25
50. Physically performing tasks in the lab helped me better understand how to measure carbonate system variables.	77	25
51. It was difficult to get accurate results.	71	22
52. I believe with practice I could consistently get more accurate results.	73	23
53. I could apply what I learned without significant additional training.	58	28
54. I would like to know more about performing these tasks.	61	27
55. If I needed more information, I feel I would know where to look for it.	75	18
56. My educational background was relevant to helping me perform these tasks.	72	27
57. Based on my professional experience, I felt well-prepared to perform these tasks.	72	25
58. This work would be better suited for someone with a more relevant educational background or professional experience.	49	33

[1] Mean response ratings on 100-point scale from 1 “strongly disagree” to 100 “strongly agree.”

Table A.9 Workshop satisfaction results.
Participant responses to statements evaluating satisfaction with the training (n = 16).

	Average rating of statement agreement and standard deviation[2]	
	$\bar{x}$	S.D.
59. The facilities were appropriate.	86	10
60. Information was communicated clearly.	74	24
61. The field sample collection was useful.	57	28
62. The webinars were useful.	63	36
63. The lectures were useful.	85	21
64. The lab sessions were useful.	78	19
65. I learned a lot from the workshop.	80	25
66. The workshop was worthwhile.	80	26
67. I would recommend this workshop to my colleagues.	77	25

[1] Mean response ratings on 100-point scale from 1 “strongly disagree” to 100 “strongly agree.”

Table A.10 Learning needs results.
Participant responses to statements evaluating remaining learning needs as a direct result of participating in the workshop (*n* = 18).

	Average rating of statement agreement and standard deviation[2]	
	$\bar{x}$	S.D.
24. I have utilized or referenced skills or information I learned from the workshop generally, in any context.	64	29
25. I have encountered or identified gaps in my knowledge that I would not have previously recognized.	81	20
26. I have independently read/researched additional information about OA in general.	59	33
27. I have independently read/researched additional information about marine carbonate chemistry specifically.	39	31
28. I am interested in additional learning/training opportunities regarding OA or marine carbonate chemistry.	81	19
29. I feel I still need additional learning/training opportunities regarding OA or marine carbonate chemistry.	86	15
30. I feel more confident in what I do know, as well as what I don't know, about OA or marine carbonate chemistry.	77	17
31. If I were to seek out additional information about OA or marine carbonate chemistry, I would know where to look.	78	15
32. I have adequate access to the additional information or resources I would need.	72	21
33. The information or resources I have encountered are difficult to understand or interpret.	63	24
34. If I encountered information that was difficult to understand or interpret, I would be able to figure it out.	69	23

[1] Mean response ratings on 100-point scale from 1 "strongly disagree" to 100 "strongly agree."

Table A.11 Talking statements results.
Participant responses to statements evaluating changes in how much they talk about OA and MCC as a direct result of attending the workshop (n = 18).

	Average rating of statement agreement and standard deviation[2]	
	$\bar{x}$	S.D.
I find I have been talking about ocean acidification…		
35. in general	65	16
36. with my colleagues or co-workers	64	17
37. with my stakeholders and/or the public	64	19
I find I have been talking about marine carbonate chemistry, or measuring carbonate chemistry values…		
38. in general	56	9
39. with my colleagues or co-workers	59	13
40. with my stakeholders and/or the public	54	8

[1] Mean response ratings on 100-point scale from 1 "A lot less" to 100 "A lot more."

Table A.12 Long-term interactions outcomes results.
Participant responses to statements evaluating changes in interactions as a direct result of participating in the workshop (n = 18).

	Average rating of statement agreement and standard deviation[2]	
	$\bar{x}$	S.D.
41. When I talk about OA generally, what I talk about or the way I talk about it is different.	63	19
42. When I talk about marine carbonate chemistry, what I talk about or the way I talk about it is different.	64	20
43. I have more confidence in my ability to explain OA to someone else.	68	22
44. I have more confidence in my ability to explain how we measure marine carbonate chemistry values to someone else.	66	19
45. I am more likely to show someone else how to work with relevant instrumentation or data.	56	23

[1] Mean response ratings on 100-point scale from 1 "strongly disagree" to 100 "strongly agree."

Table A.13 Decision-making outcomes results.
Participant responses to statements evaluating changes in decision-making as a direct result of participating in the workshop (*n* = 18).

	Average rating of statement agreement and standard deviation[2]	
	$\bar{x}$	S.D.
46. I have a better idea of what resources or activities to focus on when it comes to my role in measuring, monitoring, mitigating, or managing OA.	74	18
47. I have considered altering the scope, breadth, depth, or focus of some aspect of my work/project(s).	58	24
48. I have thought about changing the way I do something at work based on information or skills I learned from the workshop.	59	25
49. I have made a decision differently of changed the way I do something at work based on information or skills I learned from the workshop.	54	25
50. I have considered changes to employee responsibilities or how to make staffing/hiring decisions differently.	37	23
51. I would need to learn or understand more about OA or marine carbonate chemistry before making any changes.	47	22

[1] Mean response ratings on 100-point scale from 1 “strongly disagree” to 100 “strongly agree.”

Table A.14 Instrumentation and data results.
Participant responses to statements evaluating changes in decision-making as a direct result of participating in the workshop (*n* = 18).

	Average rating of statement agreement and standard deviation[2]	
	$\bar{x}$	S.D.
52. I have more confidence in my understanding of how marine carbonate chemistry values are measured.	73	22
53. I find myself thinking more about changing the way I work with instrumentation or data.	55	26
54. I am making changes to the way I work with instrumentation or data.	48	24
55. I find myself thinking more about acquiring new/different instrumentation.	56	30
56. I am making real efforts to acquire new instrumentation.	43	35
57. I find myself looking for more opportunities to train or help others with using instrumentation or data.	41	29
58. I have changed my thinking about the need for certain kinds of instrumentation or data.	58	27

[1] Mean response ratings on 100-point scale from 1 “strongly disagree” to 100 “strongly agree.”

APPENDIX J: RESEARCH DESIGN VALIDITY MATRIX

Table A.15 Research design validity matrix
(adapted from Maxwell, 2012)

1. What do I need to know?	2. Why do I need to know this?	3. What kind of data will answer the questions?	4. Analysis Plans	5. Validity Threats	6. Possible strategies for dealing with validity threats	7. Rationale for strategies
RQ 1: What do marine resource managers know about OA and marine carbonate chemistry?	Manager knowledge of OA and MCC is undescribed in the literature Designing an educational intervention targeting this knowledge requires understanding the baseline	Likert-type scale responses and multiple-choice assessments from questionnaires	Descriptive statistics	Criterion validity	Assess self-reported perceptions of knowledge followed by assessment of factual knowledge	Participants may over or underestimate their perceptions of their own knowledge. Providing a factual knowledge assessment of their own knowledge will corroborate these perceptions with a demonstration of their actual level of knowledge.
RQ 2: How does a hands-on experiential learning program focused on OA and marine carbonate chemistry change this knowledge?	Allows assessment of manager post-training knowledge and the effectiveness of the educational intervention Informs curricular refinement	Likert-type scale responses and multiple-choice assessments from questionnaires Open-ended essay questions and semi-structured interview questions	Parametric and nonparametric pairwise comparison tests of repeated measures Axial and thematic coding	Instrumentation Maturation Experimenter effects	Knowledge question form and order will be presented unchanged in all iterations of the survey, pre and post training Participants will be asked if they have viewed the webinars, or participated in any similar webinars or trainings in the intervening weeks Use of open-ended and interview questions, which address similar concepts throughout, to minimize indications of researcher bias. Interviews cease once theoretical saturation is reached (Miles et al., 1994).	Participants may provide inconsistent ratings or responses to questions if not presented in identical fashion for each iteration. Delivering surveys before and after educational intervention demonstrates effects of that intervention. Participant knowledge could be influenced externally if they participate in some other concurrent educational intervention (such as C-CAN). Individual perspectives may be used to identify the bounds of intervention effects but capturing and describing the impacts writ large requires generalizing participant responses via thematic data reduction.
RQ 3: How might it influence their management behaviors and decision-making?	The goal of professional development training is to enhance real-world implementation of the knowledge and learned.	Likert-type scale responses Open-ended essay questions and	Descriptive statistics Axial and thematic coding	Reactivity Experimenter effects	Use of open-ended and interview questions, which address similar concepts throughout, to minimize indications of researcher	Respondents may be inclined to provide socially-desirable responses which can be corroborated across survey and interview responses. Greater emphasis on open-ended

	Assessing this outcome helps validate the success of the training program	semi-structured interview questions		Hawthorne effects	bias. Interviews cease once theoretical saturation is reached (Miles et al., 1994). Follow-up interviews used as a check on claims of behavioral change. Survey prompt explaining categories of behavioral change provided to capture different types.	questions delivered via online survey minimizes inclination to please researcher. Individual perspectives may be used to identify the bounds of intervention effects but capturing and describing the impacts writ large requires generalizing participant responses via thematic data reduction and minimizes influence of researcher. Respondents may be more likely to report behavioral changes as a result of awareness they are being studied. Conversely, they may underreport behavioral changes unless prompted to understand different categories and descriptions of what classifies as a change in behavior.
RQ 4: What are the best methods for testing and evaluating this kind of program?	Understanding how to construct an evaluation that is tuned for a particular educational program aids in development of that program by manifesting strengths and weaknesses	Likert-type scale responses Open-ended essay questions	Parametric and nonparametric pairwise comparison tests of repeated measures Axial and thematic coding	Reactivity Experimenter effects	Use of open-ended and interview questions, which address similar concepts throughout, to minimize indications of researcher bias. Interviews cease once theoretical saturation is reached (Miles et al., 1994). Questionnaires designed to capture concepts through differing types of questions and delivered online to minimize influence and interaction with researchers or fellow participants and facilitate more honest responses.	Respondents may be inclined to provide socially-desirable responses which can be corroborated across survey and interview responses. Greater emphasis on open-ended questions delivered via online survey minimizes inclination to please researcher. Individual perspectives may be used to identify the bounds of intervention effects but capturing and describing the impacts writ large requires generalizing participant responses via thematic data reduction and minimizes influence of researcher

APPENDIX K: LECTURE AND LABORATORY REFERENCES

Albright, R., Caldeira, L., Hosfelt, J., Kwiatkowski, L., Maclaren, J. K., Mason, B. M., . . . Ricke, K. L. (2016). Reversal of ocean acidification enhances net coral reef calcification. *Nature, 531*(7594), 362.

Barton, A., Hales, B., Waldbusser, G. G., Langdon, C., & Feely, R. A. (2012). The Pacific oyster, Crassostrea gigas, shows negative correlation to naturally elevated carbon dioxide levels: Implications for near-term ocean acidification effects. *Limnology and oceanography, 57*(3), 698-710.

Chan, F., Barth, J., Blanchette, C., Byrne, R., Chavez, F., Cheriton, O., . . . Gouhier, T. (2017). Persistent spatial structuring of coastal ocean acidification in the California Current System. *Scientific Reports, 7*(1), 2526.

Comeau, S., Cornwall, C. E., DeCarlo, T. M., Krieger, E., & McCulloch, M. T. (2018). Similar controls on calcification under ocean acidification across unrelated coral reef taxa. *Global change biology, 24*(10), 4857-4868.

Dawson, T. P., Jackson, S. T., House, J. I., Prentice, I. C., & Mace, G. M. (2011). Beyond predictions: biodiversity conservation in a changing climate. *Science, 332*(6025), 53-58.

Doney, S. C. (2006). The dangers of ocean acidification. *Scientific American, 294*(3), 58-65.

Doney, S. C., Balch, W. M., Fabry, V. J., & Feely, R. A. (2009). Ocean acidification: a critical emerging problem for the ocean sciences. *Oceanography, 22*(4), 16-25.

Gattuso, J.-P., Mach, K. J., & Morgan, G. (2013). Ocean acidification and its impacts: an expert survey. *Climatic Change, 117*(4), 725-738.

Gobler, C. J., & Baumann, H. (2016). Hypoxia and acidification in ocean ecosystems: coupled dynamics and effects on marine life. *Biology letters, 12*(5), 20150976.

Hutchins, D. A., Fu, F., Walworth, N. G., Lee, M. D., Saito, M. A., & Webb, E. A. (2017). Comment on "The complex effects of ocean acidification on the prominent N2-fixing cyanobacterium Trichodesmium". *Science, 357*(6356), eaao0067.

Jokiel, P. (2013). Coral reef calcification: carbonate, bicarbonate and proton flux under conditions of increasing ocean acidification. *Proceedings of the Royal Society B: Biological Sciences, 280*(1764), 20130031.

Kroeker, K. J., Kordas, R. L., Crim, R., Hendriks, I. E., Ramajo, L., Singh, G. S., . . . Gattuso, J. P. (2013). Impacts of ocean acidification on marine organisms:

quantifying sensitivities and interaction with warming. *Global change biology, 19*(6), 1884-1896.

Kroeker, K. J., Micheli, F., & Gambi, M. C. (2013). Ocean acidification causes ecosystem shifts via altered competitive interactions. *Nature Climate Change, 3*(2), 156.

Liu, X., Byrne, R. H., Lindemuth, M., Easley, R., & Mathis, J. T. (2015). An automated procedure for laboratory and shipboard spectrophotometric measurements of seawater alkalinity: Continuously monitored single-step acid additions. *Marine Chemistry, 174*, 141-146.

Lord, J. P., Barry, J. P., & Graves, D. (2017). Impact of climate change on direct and indirect species interactions. *Marine Ecology Progress Series, 571*, 1-11.

Mackey, K. R., Morris, J. J., Morel, F. M., & Kranz, S. A. (2015). Response of photosynthesis to ocean acidification. *Oceanography, 28*(2), 74-91.

Marshall, K. N., Kaplan, I. C., Hodgson, E. E., Hermann, A., Busch, D. S., McElhany, P., . . . Fulton, E. A. (2017). Risks of ocean acidification in the California Current food web and fisheries: ecosystem model projections. *Global change biology, 23*(4), 1525-1539.

Munday, P. L., Dixson, D. L., Donelson, J. M., Jones, G. P., Pratchett, M. S., Devitsina, G. V., & Døving, K. B. (2009). Ocean acidification impairs olfactory discrimination and homing ability of a marine fish. *Proceedings of the National Academy of Sciences, 106*(6), 1848-1852.

Nagelkerken, I., & Connell, S. D. (2015). Global alteration of ocean ecosystem functioning due to increasing human CO2 emissions. *Proceedings of the National Academy of Sciences, 112*(43), 13272-13277.

Nilsson, G. E., Dixson, D. L., Domenici, P., McCormick, M. I., Sørensen, C., Watson, S.-A., & Munday, P. L. (2012). Near-future carbon dioxide levels alter fish behaviour by interfering with neurotransmitter function. *Nature Climate Change, 2*(3), 201.

Pespeni, M., Chan, F., Menge, B., & Palumbi, S. (2013). Signs of adaptation to local pH conditions across an environmental mosaic in the California Current Ecosystem: Oxford University Press.

Pörtner, H. O., Langenbuch, M., & Reipschläger, A. (2004). Biological impact of elevated ocean CO 2 concentrations: lessons from animal physiology and earth history. *Journal of Oceanography, 60*(4), 705-718.

Riebesell, U., & Gattuso, J.-P. (2014). Lessons learned from ocean acidification research. *Nature Climate Change, 5*(1), 12.

Rost, B., Riebesell, U., & Sültemeyer, D. (2006). Carbon acquisition of marine phytoplankton: effect of photoperiod length. *Limnology and oceanography, 51*(1), 12-20.

Sett, S., Bach, L. T., Schulz, K. G., Koch-Klavsen, S., Lebrato, M., & Riebesell, U. (2014). Temperature modulates coccolithophorid sensitivity of growth, photosynthesis and calcification to increasing seawater pCO2. *PLoS one, 9*(2), e88308.

Vargas, C. A., Lagos, N. A., Lardies, M. A., Duarte, C., Manríquez, P. H., Aguilera, V. M., . . . Dupont, S. (2017). Species-specific responses to ocean acidification should account for local adaptation and adaptive plasticity. *Nature ecology & evolution, 1*(4), 0084.

Waldbusser, G. G., Hales, B., Langdon, C. J., Haley, B. A., Schrader, P., Brunner, E. L., . . . Gimenez, I. (2015). Saturation-state sensitivity of marine bivalve larvae to ocean acidification. *Nature Climate Change, 5*(3), 273.

Wittmann, A. C., & Pörtner, H.-O. (2013). Sensitivities of extant animal taxa to ocean acidification. *Nature Climate Change, 3*(11), 995.