Journal of Environmental Studies and Sciences
https://doi.org/10.1007/s13412-020-00605-w

ENVIRONMENTAL EDUCATION

Learning to be an interdisciplinary researcher: incorporating training about dispositional and epistemological differences into graduate student environmental science teams

David C. Gosselin[1] · Kate Thompson[2] · Deana Pennington[3] · Shirley Vincent[4]

Abstract
The interdisciplinary research (IR) that is necessary for the creation of innovative solutions for the many complex environmental challenges facing society requires collaboration and the sharing and integration of knowledge from different disciplines in teams. Higher education programs should deploy effective pedagogical approaches to train students in interdisciplinary, team research collaboration. This paper discusses the design of three learning modules that supported the development of collaboration and teamwork skills among doctoral students during an IR workshop held in 2017 at the University of Texas at El Paso. The module activities were scaffolded to provide multiple opportunities for students to develop knowledge about the impacts that individual dispositional characteristics and differences in epistemological philosophies can have on teamwork processes. The activities and the workshop overall created opportunities for the students to apply this knowledge in a variety of authentic, collaborative contexts. An inquiry approach to pedagogical practice was used to address two key questions: (1) Did the learning modules increase knowledge of the impact of sharing dispositional features of team members on the practice of IR? (2) How confident were workshop participants in their ability to adapt to dispositional and epistemological diversity during future IR team activities? Results from a post-workshop questionnaire data, group reflections, and retrospective pre- and post-assessment showed (1) participants learned and practiced essential collaborative skills in authentic contexts; (2) the modules were valued and helped participants recognize the important role that personal dispositional characteristics have on the development of effective IR teams; (3) participants' confidence in adapting to differences among team members increased; and (4) participants recognized that effective collaboration is an emergent property of a team that benefits from the overall intentionality of using a defined process and communication strategy.

Keywords Collaboration · Teamwork · Interdisciplinary research skills · EMBeRS · Dispositional characteristics · Dispositional distance · Team science

Introduction

Society faces many wicked problems related to the environment including understanding and mitigating impacts from climate change, sustaining food-energy-water systems, avoiding depletion of natural resources, and preserving biodiversity, among many others. Wicked problems are complex and are characterized by legitimate, competing values of

✉ David C. Gosselin
dgosselin2@unl.edu

Kate Thompson
kate.j.thompson@qut.edu.au

Deana Pennington
ddpennington@utep.edu

Shirley Vincent
shirleygvincent@gmail.com

[1] Environmental Studies Program & School of Natural Resources, University of Nebraska-Lincoln, 150 Hardin Hall, 3310 Holdrege, Lincoln, NE 68583-0996, USA

[2] School of Education and Professional Studies, Queensland University of Technology, Kelvin Grove, Brisbane, QLD 4059, Australia

[3] Department of Geological Sciences, University of Texas at El Paso, El Paso, TX 79968, USA

[4] Vincent Evaluation Consulting, 1216 E. 28th Street, Tulsa, OK 74114, USA

Published online: 22 April 2020

stakeholders; difficult to predict cause and effect relationships; high degrees of uncertainty; and multilevel social interactions (Rittel and Webber 1973). Higher education faces many challenges in preparing students to address wicked problems (Zemsky 2009, Soranno and Schimel, 2014, Bammer 2013, Ramaley 2014, National Research Council 2015). Developing solutions for wicked problems requires interdisciplinary and transdisciplinary research (NAS 2014). Interdisciplinary research (IR) requires collaboration, sharing of knowledge from different disciplines in teams, and convergence of expertise (e.g., Bammer 2013; Pennington 2016; Pennington et al. 2016; Guimarães et al. 2019). Effective collaboration and teamwork provide pathways for scientists, professionals, and stakeholders to integrate resources (e.g., expertise, knowledge, data, methods, and technologies) and to bridge disciplinary, sociocultural, political, and institutional boundaries to effectively address complex, multifaceted problems.

Graduates from higher education lack the teamwork skills that are necessary for their effective participation in collaborative research partnerships and teams according to many studies (PISA 2015; NAS 2012; NRC 2015). Nearly a century of psychological science has provided extensive knowledge about team-related, collaborative processes (Salas et al. 2018), yet the majority of students have not received explicit training in collaboration. Studies of science teams, in particular, indicate that there are significant challenges related to the development of effective teams (Hall et al. 2018). In addition to the importance of these skills to IR teams, the ability to work with others in collaborative, interdisciplinary/transdisciplinary problem solving teams is a valued workforce skill (Fiori et al. 2018; Weik et al., 2011, 2015; Voogt and Pareja Roblin; 2012). Weik et al. (2011, 2015) identified collaborative and participatory problem solving as key competencies needed by current and future professionals to address wicked problems related to the environment and sustainability. National industry studies have highlighted the lack of collaboration competencies broadly (NAS 2012) as well as specifically in areas such as management (AMA 2012) and science, technology, engineering, and mathematics (NRC 2015). The alignments of values, theory, epistemologies, and methods are identified challenges to the practice of interdisciplinarity (Lélé and Norgaard 2005). It is clear that educational institutions are not meeting societal needs in terms of preparation for collaboration (PISA 2015; Hart Research Associates, 2011) and that there is an urgent need for pedagogical approaches that better prepare students to collaborate—current academic curricula do not effectively incorporate collaborative processes and practices into the curriculum (Fiori et al. 2018). Current methods of training are not adequate to prepare individuals for IR, and reporting of evidence-informed approaches to teaching IR are rare (Stokols 2014; Guimarães et al. 2019).

Participation in scaffolded, project-based learning, interdisciplinary projects in tertiary contexts can be important to developing the *soft skills*—teamwork/collaboration, critical thinking/problem solving, oral communication, and creativity/innovation—needed for effective IR (Vogler et al. 2018). Explicit training in the differences between epistemological frameworks and the opportunity to practice communication across these frameworks are also important for the training of researchers and professionals engaged in IR (Killion et al. 2018).

The purpose of this paper is to describe three learning modules designed to support the development of collaboration and teamwork skills in the context of IR (Thompson et al. 2017). The modules focus on the importance of accounting for the compositional features of team members—e.g., personality, dispositions, competencies, epistemology, and demographics—as an inherent part of the collaborative process. They were incorporated into a workshop for doctoral students involved in addressing important environmental challenges such as climate change and sustainable water resources development. Learning to manage dispositional and epistemological differences among team members is important for the development of effective teams. Multiple workshop activities provided opportunities for students to apply knowledge gained from the modules in a variety of authentic, collaborative contexts.

The design of the modules used an inquiry approach (Alhadad and Thompson 2017) to address two research questions: (1) Did the modules increase knowledge of the impact that dispositional features of team members can have on the practice of IR? (2) Did the modules influence participants' confidence in their ability to adapt to dispositional and epistemological diversity during future IR team activities? Group reflections, assessment of students during the workshop, and post-workshop surveys provide information about the complex interplay of knowledge, beliefs, and motivation to the development of effective collaboration in environmental science IR teams.

Background

Team composition Effective collaboration requires the integration of individual team members into a distributed cognitive system through which data, information, tools, artifacts, etc. flow freely (Pennington 2016, Hutchins 1995). Substantial research about best practice in teams, characteristics of effective teams, processes that result in effective teamwork (Driskell et al. 2018, Mathieu et al. 2018), and collaborative research practice (National Research Council 2015) over the past 25 years has documented the importance of team composition for effective teams. Synthesis models and conceptual frameworks for team processes described by Salazar et al. (2012), Driskell et al. (2018), and Mathieu et al. (2017,

2018)—all informed by Marks et al. (2001)—highlight the importance of managing the interpersonal relationships among compositionally diverse team members to support effective teamwork. Team processes are the cognitive, verbal, and behavioral activities directed toward organizing task work to achieve collective goals (Marks et al. 2001). The conceptual framework developed by Mathieu et al. (2017, 2018) for effective teamwork includes three overlapping domains: *structural features*, e.g., context of the team setting such as members' interdependence, location, scope and task types, and roles; *compositional features of team members*, e.g., personality, dispositions, competencies, epistemology, and demographics; and *mediating mechanisms*, e.g., transition processes, action processes, and interpersonal processes.

The focus of this paper is on the compositional features of team members. Variability in these compositional features leads to diversity among team members that are emergent and dynamic as a function of team context, inputs, processes, and outcomes (Marks et al. 2001). Compositional diversity includes *surface-level* and *deep-level* personal characteristics that influence the effectiveness of deep knowledge integration (Fig. 1, Harrison et al. 2002, Salazar et al. 2012). *Surface-level* characteristics include age, race, gender, and other characteristics that are readily observable—such as skill sets and explicit knowledge along with the actions and reactions (e.g., behavioral characteristics) toward others. *Deep-level* differences include individual psychological constructs such as attitudes, preferences, beliefs, and assumptions (Harrison et al. 1998). Diversity in *deep-level* differences among team members can lead to knowledge and social gaps between individuals and the groups with which they are associated that, in turn, can reduce team effectiveness (Harrison and Klein 2007). Learning about the compositional diversity of team members as a fundamental input to a team is important for effective team outcomes (Marks et al. 2001, Salazar et al. 2012, Driskell et al. 2018, and Mathieu et al. 2018).

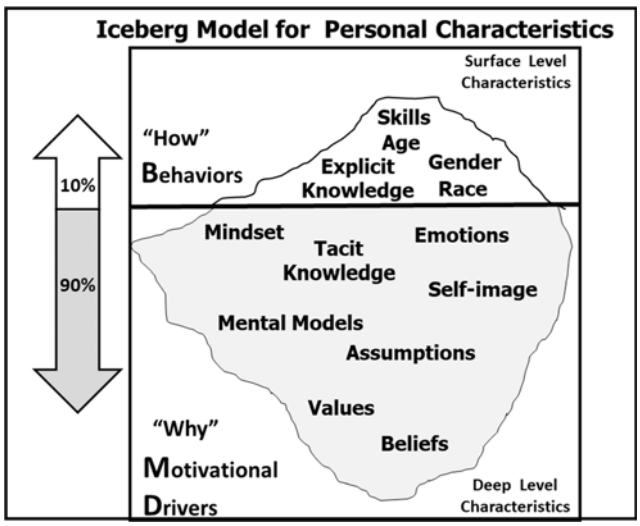


Fig. 1 There are many versions of the iceberg model. In this version, we use the metaphor of an iceberg to illustrate that there are many hidden elements and deep level characteristics that influence and drive a person's surface level characteristics that include behavioral characteristics in a diverse range of contexts

Practice and process in authentic settings A key factor in the development of effective collaboration skills is to have multiple opportunities to practice them in authentic contexts (Fiori et al. 2018). A range of authentic educational programs promote the development of collaboration skills, including the National Institute of Health's Team Science initiatives (https://www.training.nih.gov/team_science); the National Science Foundation's Integrative Graduate Education and Research Traineeship (Martinez et al. 2006) and subsequent Research Traineeship (https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505015); and the Partnerships in International Research Education programs (Knowlton et al. 2014). The Fellowship Program developed as part of the Global Lake Ecological Observatory Network (GLEON) is a specific example of a scientist-in-training approach that engaged participants in authentic collaborative contexts (Read et al. 2016). Each program includes a collection of methods and tools intended to provide authentic team experiences, but do not necessarily explicitly engage participants in the challenges faced in collaborative teamwork related to compositional diversity.

The National Research Council (NRC 2015) summarized the specific challenges that confront science teams and identified those that impacted the participants in the authentic experiences listed above. The NRC 2015 report identified seven features that create challenges to the development of effective research collaboration and teamwork: (1) high diversity of membership; (2) deep knowledge integration; (3) large size; (4) goal misalignment; (5) permeable team and group boundaries; (6) geographic dispersion; and (7) high task interdependence. These seven features directly impact the processes in which science teams engage (NRC 2015), influence the integrative capacity necessary to produce innovation (Salazar et al. 2012), and create barriers to achieve the level of collaboration and teamwork needed for deep knowledge integration across disciplines within interdisciplinary and transdisciplinary research teams (Salazar et al. 2012; Pennington 2016; Pennington et al. 2016).

The modules described herein were developed as part of an NSF Innovations in Graduate Training NRT initiative—Employing Model-Based Reasoning in Socio-Environmental Synthesis (EMBeRS DGE−1,545,404; http://embers.cybershare.utep.edu). The EMBeRS approach provides a pedagogical design (Thompson et al. 2017; Pennington et al. 2016; Killion et al. 2018) for overcoming three of the teamwork challenges identified by the NAS: high disciplinary diversity, deep knowledge integration, and concomitant goal misalignment. The primary focus of the approach is the

development of shared mental models through the collaborative creation of boundary negotiating objects. Boundary negotiating objects are external representations of complex understandings of the phenomena of interest held by individuals and may include concept maps, simulations, documents, etc. (Pennington 2010). The EMBeRS systems-thinking approach provides a research-based, structured, participatory engagement process during which participants have multiple opportunities to practice collaboration in authentic settings. Modules on the importance of team composition; its implications for team processes; the identification and explicit application of dispositional and epistemological differences; and the necessity to navigate, negotiate, and adjust to these differences were integrated into the overall EMBeRS workshops pedagogical design.

Dispositional and epistemological differences A person's individual dispositional characteristics include beliefs, feelings, and values (motivational drivers) as well as a person's actions and reactions (behaviors) (Ajzen 2005). The concept of *dispositional distance* describes the differences in the dispositional characteristics among a group of team members (Fig. 2). The ability to understand self at a level where a person knows what they want to do and why they want to do it is one of the most challenging tasks that individuals face on their journey to becoming an effective collaborator, teammate and leader (Gosselin 2015).

Epistemological differences are another compositional characteristic that influence relationships among group members (Bammer 2013; Miller et al. 2008; Eigenbrode et al. 2007). Epistemological differences relate to different ways of knowing that result from disciplinary training, education, tools, approaches to research, conceptual frameworks, cultural backgrounds, and perspectives. Researchers and practitioners also have philosophical differences that influence the value

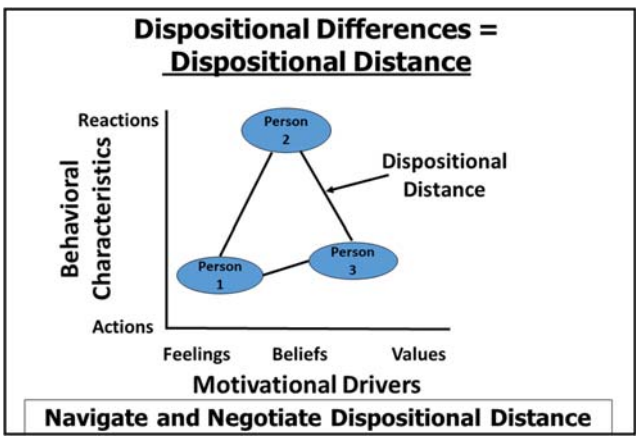


Fig. 2 A schematic representation of the differences in the behavioral characteristics and motivational drivers of team members results in dispositional distance between them that need to be navigated and negotiated throughout a collaborative project

that they place on the basic and applied components of their work as well as the extent to which they are interested in working across disciplines and with stakeholders (Eigenbrode et al. 2007; Stokols et al. 2008). Miller et al. (2008) emphasize the importance of accommodating epistemological pluralism and acknowledging that there are several valuable ways of knowing that include—but are not limited to—scientific and indigenous knowledge systems (Rathwell et al. 2015).

Addressing epistemological and dispositional characteristics of team members is a challenge because they are forms of tacit knowledge which are not easily articulated and are instead resident within the mind and perceptions of individuals (Mohajan 2016; Dampney et al. 2002). Tacit knowledge is a *deep-level* characteristic (Fig. 1). It is difficult to capture this knowledge because it is typically shared through person-to-person interaction using stories, analogies, metaphors, and discussion (Dampney et al. 2002). To assist in transitioning an individuals' tacit knowledge of their own epistemological and dispositional characteristics into more explicit knowledge, two survey instruments where used to provide the foundation for a shared experience and participatory engagement process that incorporated group reflection and small and full group dialogue.

Methods

Workshop and module design The three modules described below were embedded into two EMBeRS workshops for doctoral students conducted in 2017 (9 days) at the University of Texas at El Paso (UTEP). Thirteen individuals participated: twelve doctoral students plus a recently graduated research professor ($n = 13$). Ten of the students were recruited from NSF-funded interdisciplinary research projects related to water located at ten different US higher education institutions. Two students were doctoral students in the UTEP Interdisciplinary Environmental Science and Engineering Program. The research professor was joining the UTEP program. Based on demographic information collected from their applications, the participants had a wide range of research interests and represented a variety of disciplines in the natural sciences, social sciences, and engineering. The participants included eight women and one person each of Hispanic/Latino, Asian, and Black race/ethnicity. Three were international students from India, Nigeria, and Vietnam.

The EMBeRS workshops targeted an array of challenges related to learning in teams (Pennington et al. submitted). Each workshop consisted of three major segments: (1) generic teamwork skills, (2) convergent problem-solving skills around a water resources case study, and (3) leadership skills associated with team activity design and implementation (for a complete description, see Thompson et al. 2017). The activity-centered analysis and design (ACAD, Carvalho and

Goodyear 2014) framework supported the development of the workshop activities. The focus of this paper is on the design and evaluation of the three of the modules enacted to develop generic teamwork skills: *dispositional characteristics and the team environment parts 1 and 2 and disciplinary cultures and the team environment*. Figure 3 a–c provide the design of each module using the ACAD Framework. The two modules involving the dispositional characteristics and the team environment modules 1 and 2 were presented as two sequential sessions on the afternoon of day 2 of the workshop. The module focused on disciplinary cultures was implemented on the afternoon of day 3 of the workshop.

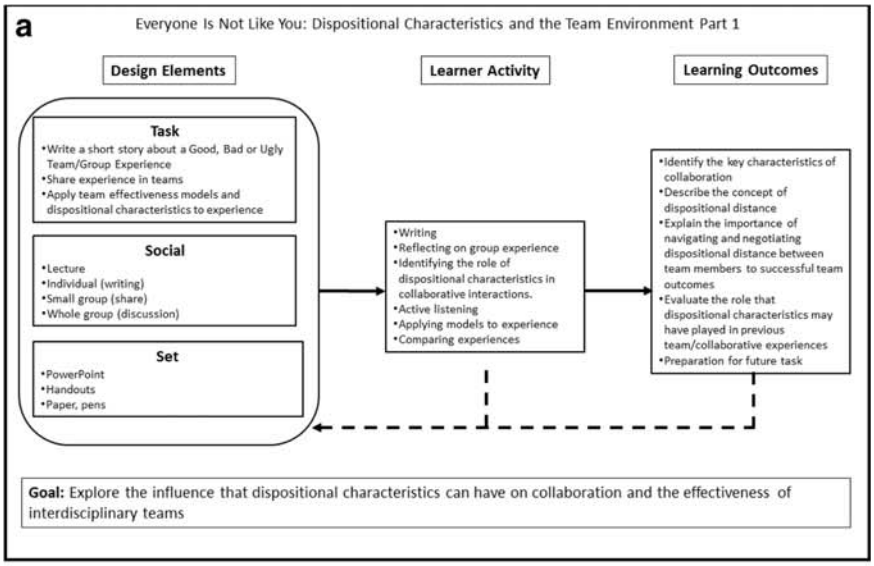
Dispositional characteristics and the team environment modules one and two The overarching goal of these two modules for the students was to explore the role of dispositional characteristics on the processes and outcomes of collaboration in interdisciplinary teams. The TriMetrix® HD assessment tool (TTISI 2012) provided the framework for the students to explore their dispositional characteristics. The TriMetrix® HD assessment tool is a psychometric tool developed by Target Training International Success Insights Ltd. (TTISI). A basic premise behind the use of this tool is that through a deeper knowledge of individual dispositional characteristics, and those of collaborators, relationships, communication and trust will grow (e.g., Lencioni 2002; Bonnstetter and Suiter 2013; Gosselin 2015). The TriMetrix® HD instrument assesses the personal attributes of the participants using self-reported data (http://www.ttiresearch.com/). The online instrument was completed by each participant prior to the workshop (typically requires 30 to 45 min). Individual TriMetrix® HD and group reports provided explicit information about the students' behavioral characteristics and motivational drivers.

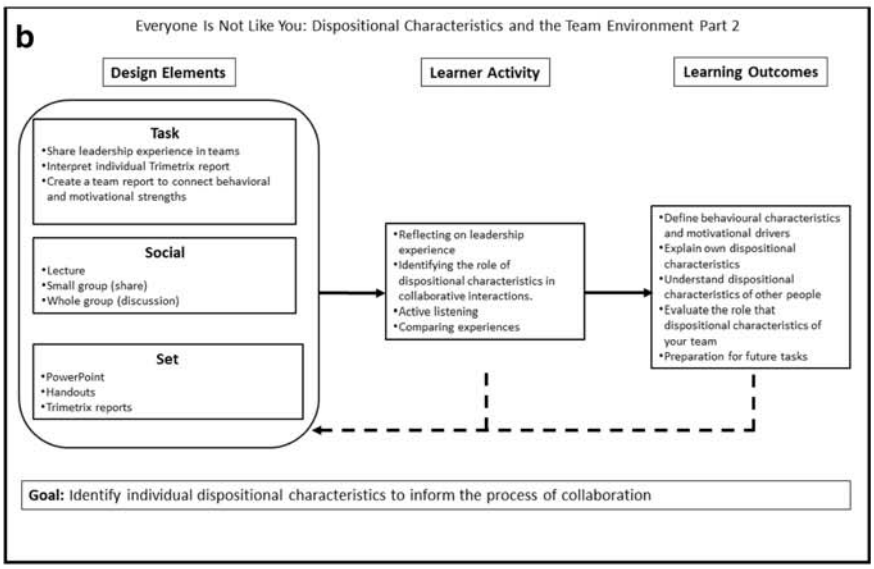
Module one—behavioral characteristics data The DISC model forms part of the TriMetrix® HD assessment. It is used to describe a person's behavioral style on a continuum of four primary behavioral dimensions D, I, S, and C (for details, see Bonnstetter and Suiter 2013): D, the way an individual manages problems/challenges and exercise power; I, how a person interacts and uses their influence with people; S, a person's steadiness, which reflects how the person responds to change, variation, and pace of their environment; and C, how an individual deals with procedures and complies with rules and other constraints that are set by others and responds to authority. The workshop students used the DISC results to learn about their behavioral characteristics in terms of "how" they carry out decisions and "how" they want to communicate. The behavior data for the 2017 cohort is presented on the TTI Success Insights Wheel® (Fig. 4). The wheel is divided into four quadrants based on the influence that the four primary behavioral dimensions—D, I, S, and C have on a person's overall behavioral characteristics. An analogy that can be used to help interpret the wheel is to imagine a magnet at D, I, S, and C: the more a dimension influences the behavior, the stronger the force of the magnet and the further person is plotted away from the center of the circle. The differential pull from the four corners results in different patterns of DISC relative to the energy line, which is the horizontal centerline, in all the small-embedded graphics on Fig. 4. The pattern associated with a person whose C dominates has a C score high above the energy line, and the D, I, and S are below the line. The core behavioral style is the highest point plotted above the energy line. The point spread between each of the behavioral dimension scores influences the tendencies for certain behavior. Each one of the numbered boxes on the Fig. 4 represent different DISC patterns. The inset graphs provide examples for areas 7, 12, 15, and 20. For more details, regarding the interpretation of the wheels, see Bonnstetter and Suiter (2013).

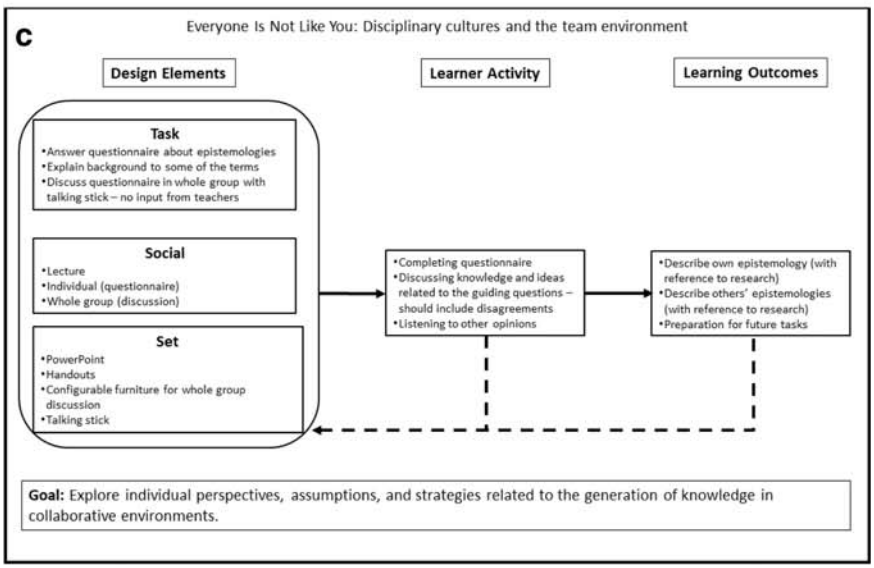
The goal of module one was to have the participants begin their exploration of the influence that dispositional characteristics can have on collaboration and the effectiveness of teams. This exploration began with a focus on concepts of collaboration, dispositional characteristics, and dispositional distance. The 1.5-h session began with individual writings followed by the sharing of stories about positive and negative group experiences. The relevance of "knowing who you are" and "knowing teammates" was put into the context of the iceberg model for personal characteristics (Fig. 1). A brief introduction to the TriMetrix® HD survey results was also provided.

Module two—motivational assessment data The DISC model provides information about behaviors and interprets "how" individuals relate and interact with each other. Motivational drivers are the "why" behind an individual's actions. The HD instrument provides information about six motivational drivers based on the descriptions of Spranger (1928):

- Theoretical—a passion for learning and wanting to learn as much as they can.
- Individualistic—a drive to control their destiny and that of others as well. They have a desire for control and recognition.
- Social—seek to give back to the community, charities, solve global social problems, etc. They are generous with their time, talents, and resources.
- Utilitarian—pursue a positive return on investment of time, energy, or money. They will focus on practical results and what is useful.
- Esthetic—seek harmonious outcomes in which life is a procession of events, each of which needs to be enjoyed for its own sake.
- Traditional—live by a certain set of standards, beliefs, or principles commonly based on family and culture.


a
Everyone Is Not Like You: Dispositional Characteristics and the Team Environment Part 1
Design Elements
Learner Activity
Learning Outcomes
Task
•Write a short story about a Good, Bad or Ugly Team/Group Experience
•Share experience in teams
•Apply team effectiveness models and dispositional characteristics to experience
Social
•Lecture
•Individual (writing)
•Small group (share)
•Whole group (discussion)
Set
•PowerPoint
•Handouts
•Paper, pens
•Writing
•Reflecting on group experience
•Identifying the role of dispositional characteristics in collaborative interactions.
•Active listening
•Applying models to experience
•Comparing experiences
•Identify the key characteristics of collaboration
•Describe the concept of dispositional distance
•Explain the importance of navigating and negotiating dispositional distance between team members to successful team outcomes
•Evaluate the role that dispositional characteristics may have played in previous team/collaborative experiences
•Preparation for future task
Goal: Explore the influence that dispositional characteristics can have on collaboration and the effectiveness of interdisciplinary teams


b
Everyone Is Not Like You: Dispositional Characteristics and the Team Environment Part 2
Design Elements
Learner Activity
Learning Outcomes
Task
•Share leadership experience in teams
•Interpret individual Trimetrix report
•Create a team report to connect behavioral and motivational strengths
Social
•Lecture
•Small group (share)
•Whole group (discussion)
Set
•PowerPoint
•Handouts
•Trimetrix reports
•Reflecting on leadership experience
•Identifying the role of dispositional characteristics in collaborative interactions.
•Active listening
•Comparing experiences
•Define behavioural characteristics and motivational drivers
•Explain own dispositional characteristics
•Understand dispositional characteristics of other people
•Evaluate the role that dispositional characteristics of your team
•Preparation for future tasks
Goal: Identify individual dispositional characteristics to inform the process of collaboration


c
Everyone Is Not Like You: Disciplinary cultures and the team environment
Design Elements
Learner Activity
Learning Outcomes
Task
•Answer questionnaire about epistemologies
•Explain background to some of the terms
•Discuss questionnaire in whole group with talking stick – no input from teachers
Social
•Lecture
•Individual (questionnaire)
•Whole group (discussion)
Set
•PowerPoint
•Handouts
•Configurable furniture for whole group discussion
•Talking stick
•Completing questionnaire
•Discussing knowledge and ideas related to the guiding questions – should include disagreements
•Listening to other opinions
•Describe own epistemology (with reference to research)
•Describe others' epistemologies (with reference to research)
•Preparation for future tasks
Goal: Explore individual perspectives, assumptions, and strategies related to the generation of knowledge in collaborative environments.

◀ **Fig. 3** Design framework for learning environment for educational modules used in the workshop. Dashed lines indicate that there is feedback from one part of the framework to another as the design evolves

Motivational drivers are those things about which a person is passionate, perceive as important, and/or are the values that provide purpose and direction in their life. These drivers strongly influence the way individuals look at life, their mindsets, and their decisions. The top two motivators—which are usually the two most important for each individual—for each of the workshop participants are shown in Fig. 5. The primary and secondary drivers for each participant are plotted in the outside and inside rings, respectively.

The goal of module two was to identify individual dispositional characteristics and to use individual results from the TriMetrix ® HD assessment to inform the process of collaboration using the context of navigating and negotiating differences among team members. During the 1.5-h session, reflective exercises provided participants with the opportunity to apply their individual dispositional characteristics to informing the process of relationship building in teams of three. An individual's general tendency to assume that everyone interacts and thinks the same way they do was addressed explicitly. Each team created "team maps" of their DISC and motivational driver information by hand plotting their group data on the wheels shown in Figs. 4 and 5. The instructor guided the small groups through the use of team blending resources (Fig. 6) that provided details regarding the strengths, weaknesses, problem-solving abilities, communication preferences, and potential areas of conflict among team members. The top diagram in Fig. 6 is an example of a resource that looks at the potential behavioral roadblocks between persuaders and coordinators (Fig. 4). In the context of

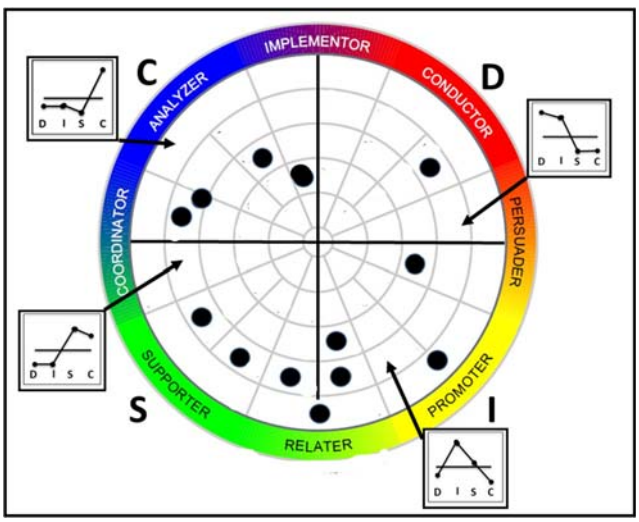


Fig. 4 Behavioral characteristics of the thirteen workshop participants. See text for details

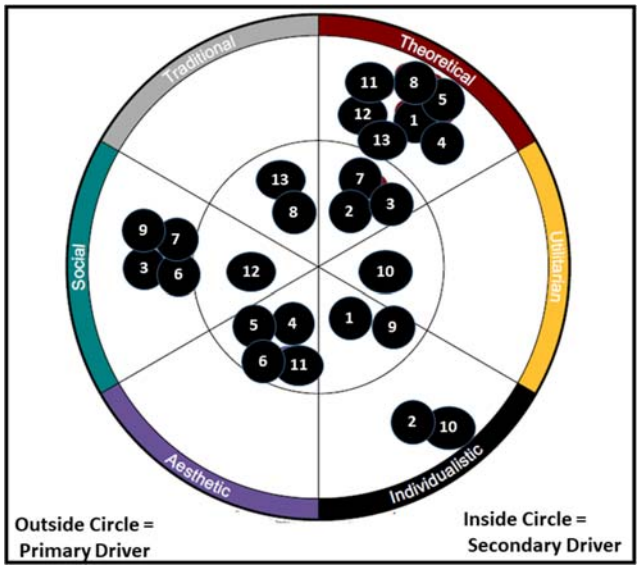
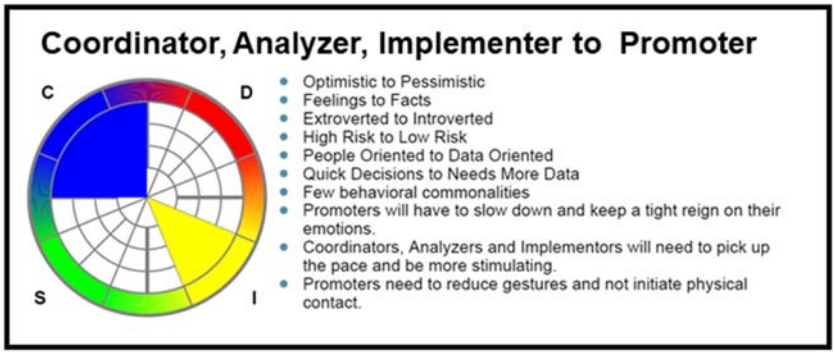


Fig. 5 Motivational characteristics for workshop participants on TTI Success Insights Motivational Drivers Wheel. The primary and secondary drivers for each participant numbered 1 to 13 are plotted in the outside and inside rings, respectively

motivational drivers, participants could have similar behavioral styles, but differences in their motivational drivers (bottom of Fig. 6) may result in a disagreement on what to do. Differences in behavioral characteristics and motivational drivers need to be negotiated to move the team forward. The exposure to these resources helped participants understand their behavioral and motivational styles in the context of developing strategies to overcome barriers to effective collaboration in their interdisciplinary research teams. Throughout the rest of the workshop, the importance of recognizing, understanding, and appreciating the different behavioral styles and motivational drivers among team members was emphasized.

Module three—disciplinary cultures and the team environment The goal of this 1.25-h module was to explore individual and group perspectives, assumptions, and strategies related to the generation of knowledge in interdisciplinary collaborative environments. The Toolbox Dialogue initiative survey (http://tdi.msu.edu/; Eigenbrode et al. 2007) provided a framework for the exploration of epistemological differences. Prior to the module, students completed a set of guiding questions from the Toolbox Dialogue initiative (http://toolbox-project.org/) to prompt dialogue about differences in disciplinary cultures. The Toolbox instrument consists of a set of elements, each comprising a core question and probing statements that concern philosophical aspects of science (Table 1). A Likert-type scale encouraged participants to take a position as a springboard for discussion. The responses to the instrument remained in the participant's possession, but they provided a framework for a 1-h, participant-driven conversation among all workshop participants. The instructors did not participate



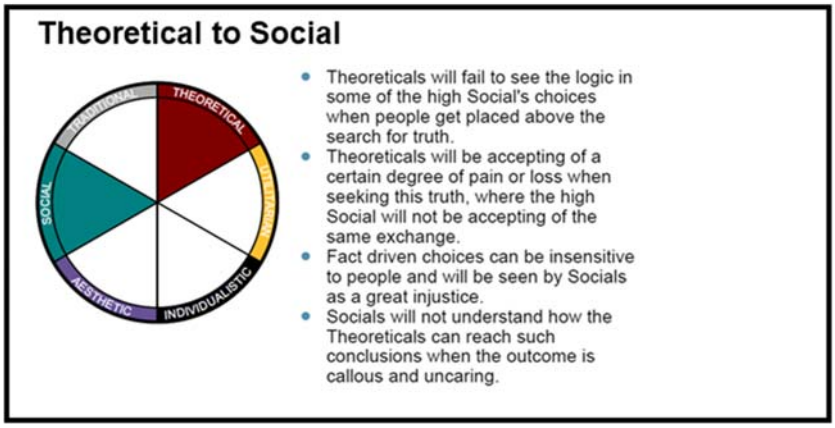


Fig. 6 Examples of TTI Success Insight Team Blending Resource materials. The top diagram examines the behavioral characteristics of participants who plot in the blue-shaded area to those in the yellow-shaded area. The bottom diagram examines differences in the motivational characteristics for participants whose primary motivational driver is theoretical compared to a person with the social driver

but allowed dialogue to continue and ensured that the conversation addressed as many questions and prompts as possible. A "talking stick" enabled equitable participation by allowing only the person holding the stick to speak. Group guidelines were established to support active listening. This conversation provided opportunities for individuals to describe and discuss their perspectives and assumptions regarding disciplinary epistemology. Broadly, the topics covered include participant perceptions of the nature of reality and scientific inquiry, the tension between qualitative and quantitative approaches, the importance and type of communication, and other deeply engrained ways of thinking that can differ between disciplinary cultures (Eigenbrode et al. 2007; Looney et al. 2013).

Data collection and analysis

Three types of data were collected and analyzed: daily group reflections, retrospective pre- and post-evaluation of the dispositional characteristics and disciplinary cultures modules, and post-workshop evaluation surveys. Approval for the study was obtained from the University of Texas El Paso Institutional Review Board (IRB study number 483287-7).

Retrospective pre- and post-module evaluation The students completed a retrospective pre- and post-assessment survey to self-identify changes in their perception of the importance of dispositional characteristics. The RPPE approach has been used to demonstrate the efficacy of educational programs since the work of Howard (1980). RPPE instruments are administered at the end of an intervention, in our case at the end of the modules, at which time the participant was asked to assess self-reported changes in knowledge, awareness, skills, or confidence. The RPPE approach asks participants to evaluate outcomes before and after an intervention using the same metric. A strength of this approach is that it controls response shift bias. This bias occurs when a participant changes their frame of reference because of their new understanding of the content. In essence, they are responding to the survey items using two different frames of reference in a traditional pre- and post-approach. Details on the pros and cons of the RPPE approach can be found in Rockwell and Kohn (1989), Hill and Betz (2005), Bursal (2015), and Malagon-Maldonado (2016), among others. Table 2 provides the retrospective evaluation survey that was used after the dispositional characteristics modules. The questions sought to examine the shift in the importance to which participants attributed each statement before and after participating in the session. These data from the survey in Table 2 were reverse scored, so the higher score indicated higher importance. For example, "very important" was scored as a 5 and "not even worth considering" scored as a 1.

Table 1 Core questions for the four elements of the Toolbox survey used in the module

Responses to sub-questions use the following Likert scale:						
Disagree	Agree					
1	2	3	4	5	I do not know	N/A
Motivation**						
Core Question: What motivates me to participate in environmental research?						
1. Knowledge generated by scientific research is valuable even if it has no application						
2. Good science products are more important to me than major funded projects						
3. Incorporating one's personal perspective in framing a research question is never valid						
4. Collaborative research should be motivated primarily by grant opportunities						
Methodology**						
Core Question: What methods do you employ in your disciplinary research (e.g., experimental, case study, observational, modeling)?						
1. Basic and applied research are equally important for environmental science research						
2. Scientific research (applied or basic) must be hypothesis driven						
3. Qualitative science is as credible as quantitative science						
4. The methods I use in my disciplinary research are easily integrated with methods used by researchers in other disciplines						
5. Experimental work conducted in the laboratory is too dependent on context to yield general principles						
6. Modeling, fieldwork, and laboratory research are of equal importance for environmental science research						
Values**						
Core Question: Do values negatively influence scientific research?						
1. Incorporating one's personal perspective in framing a research question is never legitimate						
2. Value-neutral scientific research is possible						
3. Scientists should never engage in advocacy						
4. Public outreach detracts from good science						
5. Responsible scientific research requires meeting the productivity goals of yours						
6. Scientists have a moral obligation to improve society through research						
Reality**						
Core Question: Do the products of scientific research more closely reflect the nature of the world or the researchers' perspective?						
1. Scientific research aims to identify facts about a world independent of the investigators						
2. Scientific claims need not represent objective reality to be useful						
3. Models invariably produce a distorted view of objective reality						
4. The subject of my research is a human construction						

Daily group reflections Key concepts from design-based research (Sandoval, 2014) and the ACAD framework helped to connect design and theoretical assumptions (Fig. 3) with specific design decisions (Thompson et al. 2017). In using ACAD, the design of the learning situation accounts for the following design elements: tasks (epistemic), role and rules of interactions (social), and digital and physical learning environment and tools (set); learner and instructor activity (observable behavior); as well as the learning outcomes (measurable changes over time). Conjecture mapping (Sandoval, 2014) was adapted as a method to identify and test assumptions about how the elements of the design link to activity, as well as about how the activity is linked to learning outcomes (Thompson et al. 2016; Alhadad & Thompson 2017). One of the researchers facilitated the daily reflections using three framing questions—what did you learn? What did you do? What did we intend? These became the headings of three columns drawn on the whiteboard in reverse order. The first question asked was always: What did you learn today? Students would contribute answers while the facilitator recorded them, asking for clarification at times. Sometimes the facilitator or the team would also contribute. The second question asked (the middle column) was what did you do today? The students would contribute answers that were about planned activities during the day (e.g., if they had been on a field trip) as well as more micro-level activities (e.g., listened, drew, created a concept map). The facilitator aimed to record the contributions as close to the statements by students as possible and, if paraphrasing, would check that the meaning had been captured adequately. The final question was for the facilitator (and was the first when read left to right) to outline

Table 2 Retrospective assessment: dispositional characteristics and the team environment parts one and two

Please check the box that best indicates how important you think each statement was BEFORE participating in this session and AFTER participating in this session

	BEFORE participating in this session					AFTER participating in this session				
When considering the success of your team and all that is involved in creating success, how important are the following:	1 Very Important	2 Important	3 Neutral	4 Not important	5 Not even worth considering	1 Very important	2 Important	3 Neutral	4 Not important	5 Not even worth considering
1. Knowledge of the behavioral styles and motivational drivers of your teammates	□	□	□	□	□	□	□	□	□	□
2. Knowledge of self	□	□	□	□	□	□	□	□	□	□
3. Your ability to adapt to your teammates	□	□	□	□	□	□	□	□	□	□
4. Creating a shared vision	□	□	□	□	□	□	□	□	□	□
5. Intentionally investing time to build personal relationships with your teammates	□	□	□	□	□	□	□	□	□	□
6. Communicating your strengths and weaknesses with your teammates	□	□	□	□	□	□	□	□	□	□
7. Using personal behavioral and motivational assessments in the development of interdisciplinary teams	□	□	□	□	□	□	□	□	□	□

the intended design. For most days, the students contributed to this discussion with features of the design that had emerged during the day. At the end of this exercise, the outcome was a co-created representation of the design and the implementation of the modules. It provided feedback for the designers, and it helped students reconcile often complex and intense learning experiences. In addition, the students gained insight into the purpose of the tasks they had participated in, asked questions, and made connections between what they were doing and what they were learning.

Post-workshop evaluation surveys The students also completed a post-program survey immediately following the workshop. It included questions related to the participants' confidence in their understanding and abilities to recognize the differences and adapt to behavioral characteristics and motivational drivers of team member in the future. The survey also examined the extent to which the dispositional characteristics and epistemology sessions were valued in the context of the knowledge and skill training they received via the EMBeRS workshop.

Results

RPPE RPPE data were collected from 11 of the 13 participants at the conclusion of the modules on dispositional characteristics and the team environment (Fig. 7). Of the seven items, *knowledge of self* and *creating a shared vision* were rated as the most important among the participants prior to the session, and *communicating strengths and weaknesses* and *using assessments with teammates* were rated of lowest importance. Participants' rated all seven survey items as more important after completion of the module (Table 3). Wilcoxon signed-ranks test revealed a statistically significant shift in six of the seven items following participation in the workshop modules (Table 4). The calculated effect sizes for the six of the seven items between 0.4 and 0.6 indicate that the intervention had a medium to strong influence (Table 4).

Daily group reflections The students identified key features of dispositional and epistemological differences in the group reflections carried out at the end of each day (Figs. 8 and 9). Figure 8 illustrates that students identified a range of learning outcomes from the module about dispositional differences including *trust within a team, motivation can be more important than skills and knowledge, self-awareness and awareness of others, intentional when building cooperation, and each other*. The students

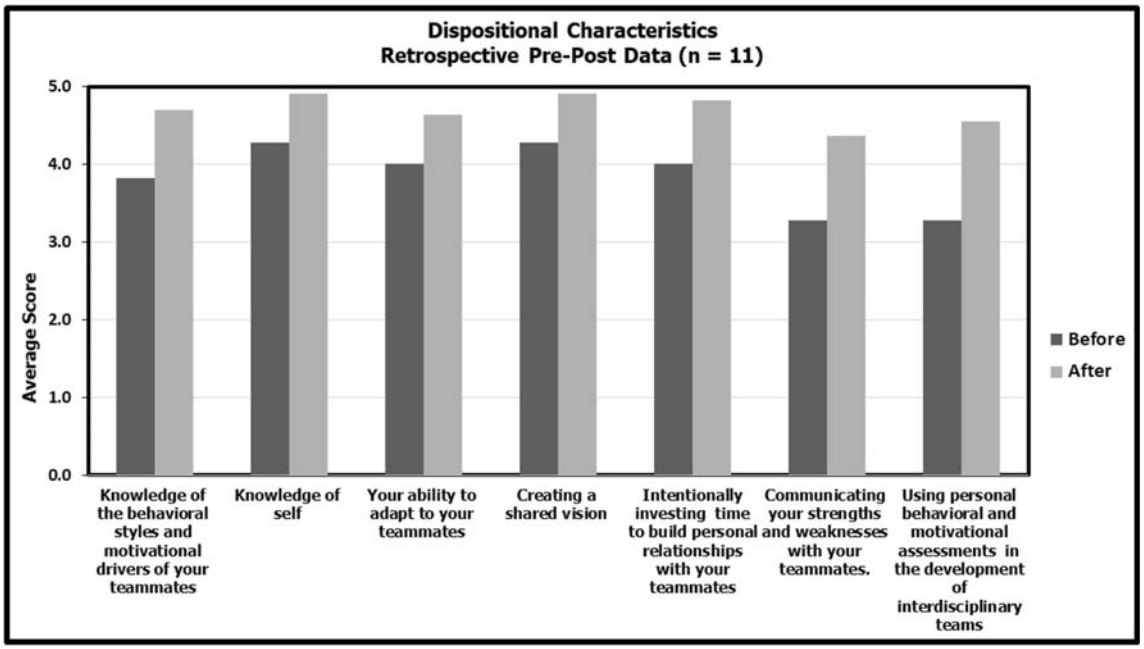


Fig. 7 Summary of the retrospective pre- and post-intervention for the dispositional characteristics and the team environment session

identified listening, collaborating, sharing personal information, and the reflections as activities that provided opportunities to apply their knowledge of dispositional differences and practice collaborative skills. One unintentional opportunity that students identified as important was informal discussions during transportation to and from the field trip during the morning workshop sessions.

Figure 9 illustrates that students identified a range of learning outcomes from the epistemic toolbox module including *ways to facilitate productive communication, fruitful debate over disagreement, shared challenges as students, shared challenges as researchers, personalities and group size matters, role of hypotheses, purpose of research, transparency* versus *objectivity, useful* versus *meaningful, epistemology, and learn about each other*. The students identified the toolbox project, the group discussion, structured dialogue, reflection, and social arrangements (such as the shared lunches) as opportunities to practice collaboration skills and apply their knowledge of both dispositional and epistemological characteristics.

Post-workshop evaluation survey Responses from all thirteen participants in the post-workshop evaluation survey indicated that the three modules were highly to very highly valued (Fig. 10a and b). In the context of future team activities, all participants indicated that they were confident to highly confident that the workshop provided them with the ability to (1) recognize the importance of differences in behavioral characteristics and motivational drivers of team member and adapt to them; (2) acknowledge the importance that different sources of knowledge can have on team success; and (3) communicate across disciplinary boundaries (Fig. 11). Participants were

Table 3 Summary of RPPE survey data

When considering the success of your team and all that is involved in creating success, how important are the following:	Pre-module Mean/SD $n = 11$	Post-module Mean/SD $n = 11$
1. Knowledge of the behavioral styles and motivational drivers of your teammates	3.8 (SD = 0.4)	4.7 (SD = 0.5)
2. Knowledge of self	4.3 (SD = 0.8)	4.9 (SD = 0.6)
3. Your ability to adapt to your teammates	4.0 (SD = 0.6)	4.6(SD = 0.5)
4. Creating a shared vision	4.3 (SD = 0.5)	4.9 (SD = 0.3)
5. Intentionally investing time to build personal relationships with your teammates	4.0 (SD = 1.0)	4.8 (SD = 0.4)
6. Communicating your strengths and weaknesses with your teammates	3.3 (SD = 0.6)	4.4 (SD = 0.5)
7. Using personal behavioral and motivational assessments in the development of interdisciplinary teams	3.3 (SD = 0.5)	4.5 (SD = 0.7)

Table 4 Wilcoxon signed-rank test of significance of change and effect sizes

	Knowledge of the behavioral styles and motivational drivers of your teammates	Knowledge of self	Your ability to adapt to teammates	Creating a shared vision	Intentionally investing time to build personal relationships with your teammates	Communicating your strengths and weaknesses with your teammates	Using personal behavior and motivational assessments in the development of interdisciplinary teams
Z	−1.44[a]	−2.07[a]	−2.33[a]	−2.65[a]	−2.26[a]	−2.46[a]	−2.89[a]
Asymp. Sig. (2-tailed)	0.150	0.038	0.020	0.008	0.024	0.014	0.004
Effect size	ns	0.44	0.50	0.56	0.48	0.52	0.62

a. Based on negative ranks .

much more confident in their abilities to understand differences than they were in their abilities to adapt and communicate across these differences.

Discussion and conclusion

Knowledge of team member composition As contemporary society seeks solutions to the many wicked problems it faces, effective collaboration and teamwork are required. It is urgent that higher education improve its pedagogical approaches to prepare students to effectively participate in collaborative interdisciplinary and transdisciplinary partnerships as well as meet workforce needs for collaboration skills (Fiori et al. 2018). A key component to preparing students to effectively participate on teams is to provide them with the opportunity to learn about the important impact that the dispositional and epistemological characteristics of team members can have on team processes. These characteristics are fundamental input parameters into any team, and diversity among team members is important for team effectiveness (Marks et al. 2001; Salazar et al. 2012; Driskell et al. 2018; Mathieu et al. 2018). The participants in the EMBeRS workshop have begun their journey to understanding the importance of learning to navigate and negotiate dispositional distances (Fig. 2) and other forms of compositional diversity (Fig. 1) as part of collaborative processes.

Evidence from the RPPE indicated that the student's perceptions about the importance and influence that the dispositional and epistemological characteristics of team members can have on team processes changed as a result of the educational intervention provided by the three modules (Tables 3 and 4). The extent to which participants valued the sessions on dispositional characteristics and disciplinary culture (Fig. 10) supports the important role of the learning modules in the workshop. The results also demonstrate the important role that reflection and discussion of dispositional and epistemological differences in the pedagogy used helped to develop collaboration skills. A key element of the design of the modules was the shared experience that the students had employing information from two survey instruments (TriMetrix® and Toolbox Survey). The person-to-person interactions and discussions of these boundary objects (objects that facilitate communication between people; Star and Griesemer 1989) are important to helping participants transition their individual tacit knowledge into more explicit knowledge about themselves (Dampney et al. 2002). Participants recognized the importance of using behavioral and motivational assessments as tools that can be used for building interdisciplinary teams (Fig. 7).

Another element of the design that supported learning about dispositional and epistemological differences (as

Design	Learner and teacher activity	Learning outcomes
Epistemic • field trip • EMBeRS • Reflective practice **Social** • morning – 2 vans (self-selected) and when whole group • lunch (self-selected) • individuals • whole group • teams (different to yesterday) **Set** • van • digital pens • notebooks • laptops • survey tool • coffee/tea • powerpoints • videos • wireless network	• listening • field trip • observing • took photos • remembered • eating • collaborating • coffee and tea • ask questions • writing • drawing • shared personal information • discovering • walking • met locals • (gender-biased transport) • reflective practice	• Trust within a team • Motivation can be more important than skills and knowledge • Dispositional distance: negotiation not change • Closing conceptual distance • Collaborative development for shared vision • How to interpret the TriMetrix® survey • Self-awareness and awareness of others • Shared language • Individual skills IN teams • Socio-political contexts in environmental decisions • Intentional when building cooperation • Role • Industry personnel understanding • River's story different depending on who • Reflective practice as a tool • Different experiences of collaboration • Water issues around El Paso • Socio-political issues around El Paso • Silos • each other • water management practices • very green lawns in El Paso • school children at the border

Fig. 8 Shared representation from the group reflection about the learning outcomes, learner activity, and design for day 2

discussed in the group reflections) was the creation of team maps (e.g., Figs. 4 and 5). These maps illustrated individual dispositions, and the blending materials provided information about how differences between individuals might manifest themselves and be enacted during group work. In the module on epistemological differences, an element of the design that was important was the use of the talking stick, which encouraged active listening and allowed participants the time to explain their individual perspectives.

Design	Learner and teacher activity	Learning outcomes
Epistemic • field trip • EMBeRS • [section moved to another day] **Social** • groups in vans • lunch groups • whole group at farm • individuals • whole group without EMBeRS • small groups (same team as yesterday) **Set** • pecan farm, drivable with lots of different things to see • talking stick • vans • water • survey • coffee • walky talky and cell phones • paper • markers • flexible furniture • venue for food • tour guides • patient drivers	• field trip • completed survey • group discussion (timed) • small group discussion • listening • summarizing on large pieces of paper • driving • asked questions • lunch (with tour guides) • co-creating takeaways • structured dialogue • writing • reflection • value sharing • social arrangements e.g. van allocations for interest, lunch inclusion of tour guides	• Pecans • Irrigation systems • Common ground between stakeholders • Ways to facilitate productive communication • Fruitful debate over disagreement • Talking stick and implications • Characteristics of the adoption of technology • Conventional tillage • Reducing complexities to meaningful representations needs dedicated attention • Other technology used for agriculture e.g. laser and GPS • Water rights in New Mexico • Shared challenges as students • Shared challenges as researchers • Importance of education in stakeholders • Personalities and group size matter in takeaways • Sensibility of orientation as research • Farming business • Metered groundwater wells • Water so rare farmers steal from each other • Hay bales can spontaneously combust • Role of hypotheses • Purpose of research • Transparency versus objectivity • Useful versus meaningful • Epistemology • Change through generations • Toolbox project/model • Learn about each other

Fig. 9 Shared representation from the group reflection about the learning outcomes, learner activity, and design for day 3

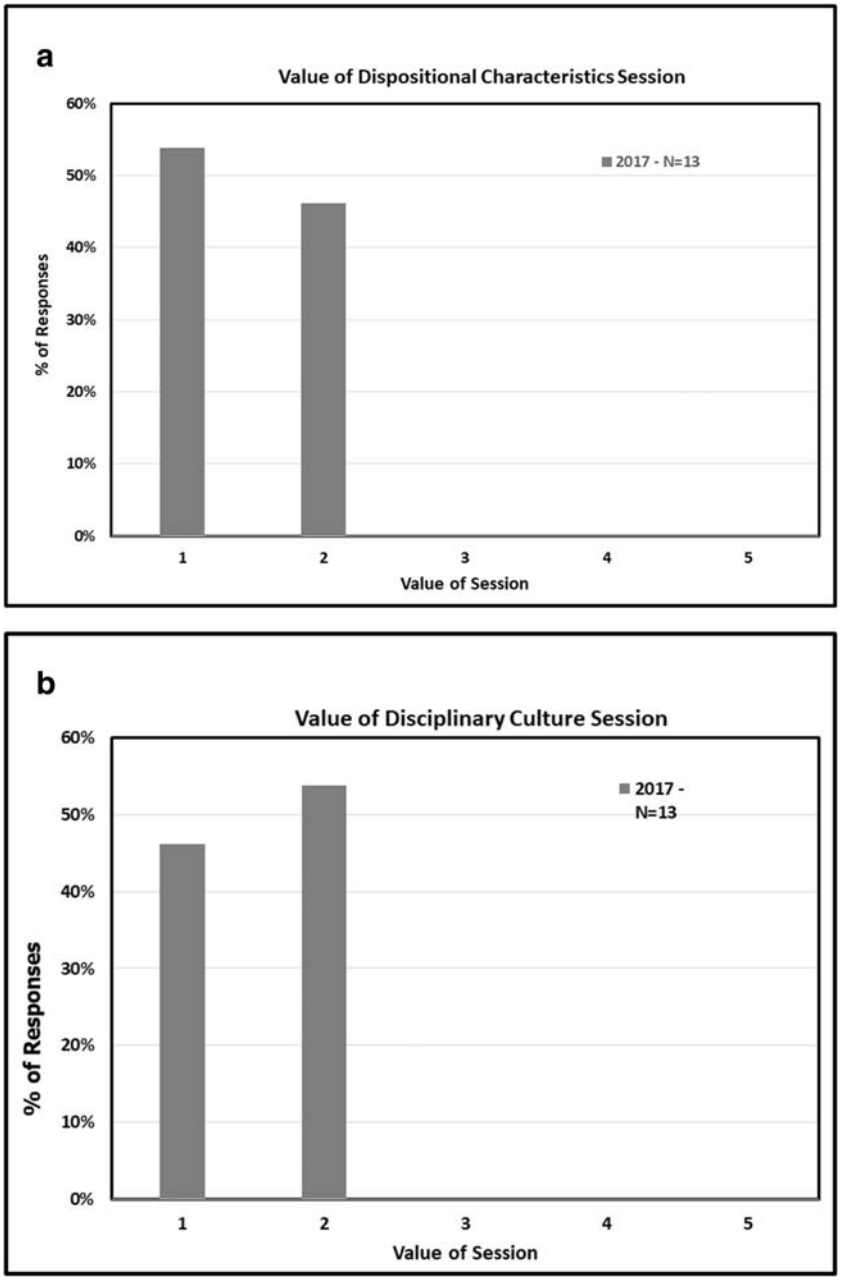


Fig. 10 Summary of the value placed on the session related to dispositional characteristics (**a**) and disciplinary culture (**b**)

Importance of process Collaboration, in its simplest form, is the process of working with another person or group of people to create, produce, or complete a task. This sounds simple, leading to the faulty assumption that effective collaboration can occur without training or instruction. One of the characteristics of effective collaboration is that it is emergent and takes time to develop (Friend and Cook 1996; Gosselin 2015). Collaboration emerges and grows as relationships develop among team members. Key considerations for productive collaboration to emerge were identified during the end-of-the-day group debriefings (Figs. 8 and 9) and included the importance of taking time to learn about team member characteristics—personalities, behaviors, their research, motivations, values, talents, and interests. Taking this time to create a safe environment that encourages the development of trust and respect is crucial for the process of developing effective teams (Lencioni 2002).

Emergence can be intentionally facilitated using a variety of processes. One of the unique attributes of the EMBeRS workshop is that the participants explicitly used a process that incorporated opportunities for them to explore dispositional characteristics and disciplinary-based cultural perspectives in the early stages of the relationship-building process. Implementation of a participatory engagement process that included group

reflection increased awareness of the participants' own characteristics and those of others in the team (Killion et al. 2018). The importance of having an intentional process (Fig. 11) for participants to explore the characteristics of themselves and their teammates is important to the emergence of collaboration in IR teams (Marks et al. 2001, Salazar et al. 2012, Gosselin 2015, Driskell et al. 2018, and Mathieu et al. 2018). The process used in the modules could be modified by others for educational initiative to demonstrate and teach how to facilitate effective IR team collaboration.

Participant confidence Data from the modules and workshop evaluation surveys and analysis of the student reflections indicate that the modules were valued (Fig. 10). They contributed to the students' confidence in their abilities to understand the differences in dispositional and disciplinary cultures of their teammates (Fig. 8). The modules enhanced the students' recognition of the important role that understanding and awareness of their own dispositional characteristic as well as those of their teammates have on the development of an effective team (Fig. 7). More importantly, these modules contributed to a generally high level of confidence in the students' abilities to adapt to differences among team members and to communicate across disciplinary boundaries in the future (Fig. 11). The students recognized the importance of the overall intentionality of the process, the intentionality of the communication strategy employed, and effective collaboration is an emergent property of a team (Killion et al. 2018).

A basic tenet of any successful educational intervention is that the participants valued the experience and that it increased their self-efficacy beliefs—i.e., the confidence that one can perform the action successfully (Bandura, 1986, 2001). This, in turn, leads to a "core belief that one has the power to produce effects by one's actions" (Bandura, 2001, p. 6). Continuing self-reported use of the EMBeRS approach by all the workshop participants in other aspects of their professional lives (Pennington et al. submitted) provides evidence that the modules and the EMBeRS workshop provided participants with the confidence to employ the approach in other situations (Killion et al., 2018; Pennington et al., 2018; Shew, 2018).

Although the implications for the generalizability of this research are limited by the small number of participants (13), the calculated effect sizes indicate that the meaningful change occurred as a result of the training provided through the three modules in the context of the EMBeRS workshop. Based on their experiences, the participants recommended embedding integrative research training into all existing graduate programs and coursework. This integration would facilitate the understanding of epistemological frameworks and prioritize teaching team science skills and methods to help students learn to navigate dispositional differences (Killion et al. 2018). This suggests that creating opportunities for students to explore processes, interactions, and resources related to dispositional and epistemological characteristics should be included in graduate and undergraduate educational experiences. Additional workshops are needed as well as testing of

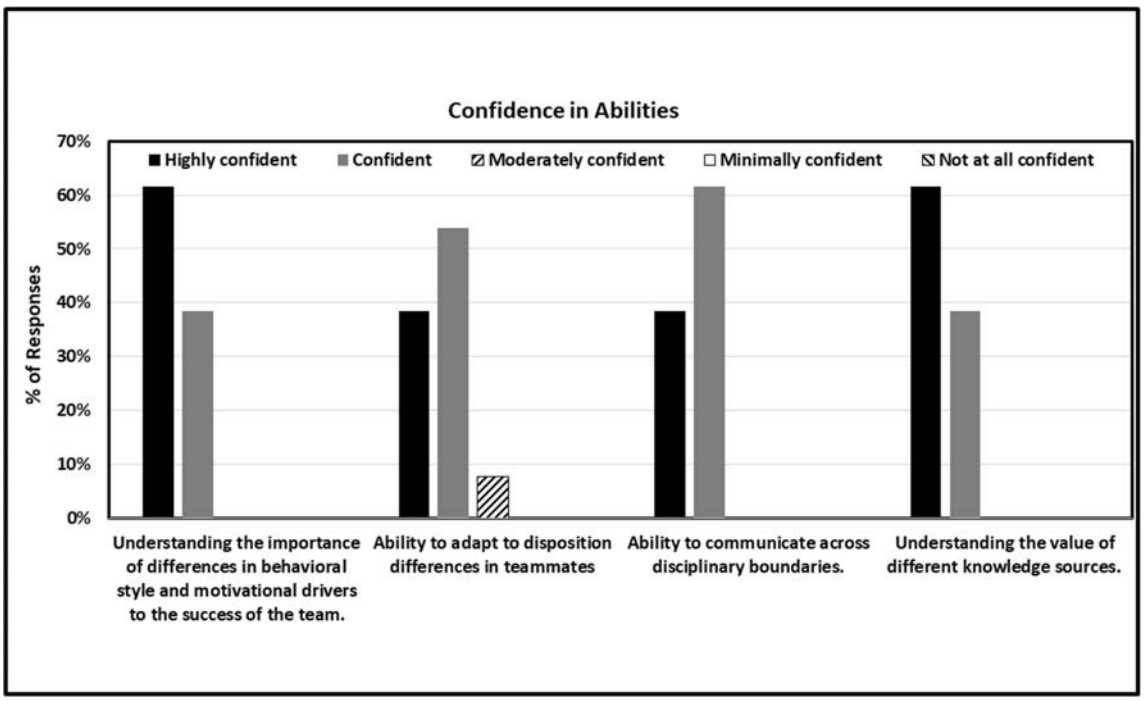


Fig. 11 Summary of the confidence level that participants of the workshop ($n = 13$) had in understanding and adapting to the dispositional and disciplinary cultures of a team as a result of training

the modules in different contexts to improve understanding and evidence of effectiveness. Broader dissemination of the three modules for interdisciplinary learning including options for online offerings is a future challenge for this group. Continued research into the complexity of interdisciplinary learning, including the role of boundary negotiating objects and reflective practice, is also needed.

The information presented in this paper supports the conclusion that the three dispositional and epistemological characteristics modules were a successful educational intervention. They successfully scaffolded the learning that allowed participants to become confident in their ability to apply what they had learned. Given multiple opportunities to observe how these differences could be used productively, the workshop participants used them to create opportunities for collaboration instead of barriers to productive collaboration. They valued these experiences and were more confident in their ability to adapt to different collaborative contexts. This work has implications for team science more broadly as scientists need the skills to identify and embrace our dispositional and epistemological differences and use them to develop solutions to wicked problems.

Acknowledgments The authors acknowledge ideas contributed by Drs. Roderic Parnell, Antje Danielson, and Geoffrey Habron that have informed this material.

Funding information This material is based upon work supported by the National Science Foundation under grant number DGE-1545404. It was also supported by the National Socio-Environmental Synthesis Center (SESYNC) under funding received from the National Science Foundation under grant number DBI-1052875 and from institutional resources through the University of Texas at El Paso and Griffith University in Australia.

References

Alhadad SJ, Thompson K (2017) Understanding the mediating role of teacher inquiry when connecting learning analytics with design for learning. Inter. Design Arch Journal 33:54–74

Ajzen I (2005) Attitude, personality, and behavior, 2nd edn. Open University Press, Berkshire

American Management Association (AMA 2012) *Critical Skills Survey* https://www.amanet.org/uploaded/2012-Critical-Skills-Survey.pdf. Last Accessed 19 December 2018

Bammer G (2013) *Disciplining interdisciplinarity: integration and implementation sciences for researching complex real-world problems*, ANU E-press, Canberra. ISBN: 9781922144270 (pbk.) 9781922144287 (ebook), http://epress.anu.edu.au/titles/disciplining-interdisciplinarity or http://press.anu.edu.au?p=222171

Bandura A (1986) Social foundations of thought and action: a social cognitive theory. Prentice Hall, Upper Saddle River

Bandura A (2001) Social cognitive theory: an agentic perspective. Annu Rev Psychol 52:1–26

Bonnstetter BJ Suiter JI (2013). DISC the universal language. *Reference Manual*. Target Training International. Scottsdale. 371p

Bursal M (2015) A comparison of standard and retrospective pre-post testing for measuring the changes in science teaching efficacy beliefs. J Balt Sci Educ 14:275–283

Carvalho L, Goodyear P (2014) The architecture of productive learning networks. Routledge, New York

Dampney CNG, Busch P, Richards D (2002) The meaning of tacit knowledge. Australas J Inf Syst 10(1). https://doi.org/10.3127/ajis.v10i1.438

Driskell JE, Salas E, Driskell T (2018) Foundations of teamwork and collaboration. Am Psychol 73(4):334–348. https://doi.org/10.1037/amp0000241

Eigenbrode SD, O'Rourke M, Wulfhorst J, Althoff DM, Goldberg CS, Merrill K, Morse W, Nielsen-Pincus M, Stephens J, Winowiecki L, Bosque-Perez NA (2007) Employing philosophical dialogue in collaborative science. BioScience 57:55–64. https://doi.org/10.1641/B570109

Fiori S, Graesser A, Grei S (2018) Collaborative problem-solving education for the twenty-first-century workforce. Nat Hum Behav 2:367–369

Friend M, Cook L (1996) Interactions: collaboration skills of school professionals, 2nd ed. White Plains, New York. Newer addition 7th. Pearson (2012). ISBN: 978-0132774925

Gosselin D (2015) Focus on them: a mindset revolution for coaches, educators, and business leaders. Aloha Publishing, Eagle ISBN: 978-1-61206-113-9

Guimarães MH, Pohlb C, Binac O, Varandae M (2019) Who is doing inter- and transdisciplinary research, and why? An empirical study of motivations, attitudes, skills, and behaviours. Futures 112. https://doi.org/10.1016/j.futures.2019.102441

Hall KL, Vogel AL, Huang GC, Serrano KJ, Rice EL, TsakraklidesSP FSM (2018) The science of team science: a review of the empirical evidence and research gaps on collaboration in science. Am Psychol 73(4):532–548. https://doi.org/10.1037/amp0000319

Howard GS (1980) Response-shift bias: a problem in evaluating interventions with pre/post self-reports. Eval Rev 4:93–106

Harrison DA, Price KH, Bell MP (1998) Beyond relational demography: time and the effects of surface- and deep-level diversity on work group cohesion. Acad Manag J 41:96–107

Harrison DA, Price KH, Gavin JH, Florey AT (2002) Time, teams, and task performance: changing effects of surface- and deep-level diversity on group functioning. Acad Manag J 45(5):1029–1045. https://doi.org/10.2307/3069328

Harrison DA, Klein KJ (2007) What's the difference? Diversity constructs as separation, variety, or disparity. Acad Manag Rev 32(4):1199–1228

Hart Research Associates (2011) Falling short? College learning and career success. Report for Association of American Colleges and Universities. https://www.aacu.org/sites/default/files/files/LEAP/2015employerstudentsurvey.pdf, Last accessed 20 December 2018

Hill LG, Betz DL (2005) Revisiting the retrospective pretest. Am J Eval 26:501–507

Hutchins E (1995) Cognition in the wild. MIT Press, Cambridge, 381 p

Killion AK, Sterle K, Bondank E, Drabik J, Bera A, Alian S, Goodrich K, Hale M, Myer RA, Phung Q, Shew AM, Thayer AW (2018) Preparing the next generation of sustainability scientists. Ecol Soc 23(4):39. https://doi.org/10.5751/ES-10395-230439

Knowlton JL, Halvorsen KE, Handler RM, O'Rourke MR (2014) Teaching interdisciplinary sustainability science teamwork skills to graduate students using in-person and web-based interactions. Sustainability 6:9428–9440

Lélé S, Norgaard RB (2005) Practicing interdisciplinarity. Bioscience 55(11):967–975

Lencioni P (2002) The five dysfunctions of a team. Jossey-Bass ISBN 0-7879-6075-6

Looney C, Donovan S, O'Rourke MR, Crowley S, Eigenbrode SD, Rotschy L, Bosque-Perez NA, Wulfhorst JD (2013) Seeing through the eyes of collaborators: using toolbox workshops to enhance cross-disciplinary communication. In: O'Rourke MR, Crowley S, Eigenbrode SD, Wulfhorst JD (eds) Enhancing communication

and collaboration in interdisciplinary research, 1st edn. Sage Publications, Thousand Oaks, pp 220–243

Malagon-Maldonado (2016) Retrospective preevaluation-postevaluation in health design. Health Environ. Res. Design Journal 10(1):13–22. https://doi.org/10.1177/1937586716665032

Marks MA, Mathieu JE, Zaccaro SJ (2001) A temporally based framework and taxonomy of team processes. Acad Manag Rev 26(3): 356–376

Martinez A, Chase A, Carney J, Boulay B, Chawla D, Layzer L, Litin L, Zotov N, Goldsmith S, Haviland D (2006) Contractor annual report and summary of the cross-site monitoring of the NSF Integrative Graduate Education and Research Traineeship (IGERT) program: final report. ABTAssociates, Cambridge

Mathieu JE, Hollenbeck JR, van Knippenberg D, Ilgen DR (2017) A century of work teams in the journal of applied psychology. J Appl Psychol 102(3):452–467. https://doi.org/10.1037/apl0000128

Mathieu JF, Wolfson MA, Park S (2018) The evolution of work team research since Hawthorne. Am Psychol 73(4):308–321

Miller TR, Baird TD, Littlefield CM, Kofinas G, Chapin F III, Redman CL (2008) Epistemological pluralism: reorganizing interdisciplinary research. Ecol Soc 13(2):46–63

Mohajan HK (2016) Sharing of tacit knowledge in organizations: a review. American Journal of Computer Science and Engineering 3(2):6–19

National Academies of Sciences (2012) Engineering, and medicine education for life and work: transferable knowledge and skills in the 21st century. National Academies Press: Washington DC https://doi.org/10.17226/13398

National Academy of Sciences (2014) Convergence: facilitating transdisciplinary integration of life sciences, physical sciences, engineering, and beyond, National Academy of Sciences, National Academy of Engineering, Institute of Medicine, National Research Council, 4 p

National Research Council (2015) *Enhancing the effectiveness of team science*., Committee on the Science of Team Science (NJ Cooke & M L Hilton, Eds.): Washington D.C., The National Academies Press, Board on Behavioral, Cognitive, and Sensory Sciences, Division of Behavioral and Social Sciences and Education, 268 p. https://doi.org/10.17226/19007

Pennington D (2010) The dynamics of material artifacts in collaborative research teams. Comput Supported Coop Work 19:175–199

Pennington D (2016) A conceptual model for knowledge integration in interdisciplinary teams: orchestrating individual learning and group processes. J Environ Stud Sci 6:300–312. https://doi.org/10.1007/s13412-015-0354-5

Pennington D, Bammer G, Danielson A, Gosselin D, Gouvea J, Habron G, Hawthorne D, Parnell R, Thompson K, Vincent S, Wei C (2016) National The EMBeRS project: employing model-based reasoning in socio-environmental synthesis. J Environ Stud Sci 6. https://doi.org/10.1007/s13412-015-0335-8

Pennington D, Bondank E, Clifton J, Killion A, Salas K, Shew A, Sterle K, Wilson B (2018) EMBeRS: an approach for igniting participatory learning and synthesis. In: Arabi M, Carlson DO, Ames DP (eds) *Proceedings of the 9th International Congress on Environmental Modelling and Software*. International Association of Environmental Modelling and Software, Fort Collins

Programme for International Student Assessment (PISA) (2015) *PISA 2015 Results (Volume V): Collaborative Problem Solving Organization for Economic Cooperation and Development*. https://doi.org/10.1787/9789264285521-en

Ramaley JA (2014) The changing role of higher education: learning to deal with wicked problems. J. Higher Ed. Outreach and Engagement 18(3):7

Rathwell DA, Armitage D, Fikert B (2015) Bridging knowledge systems to enhance governance of the environmental commons: a typology of settings. Int J Commons 9(2):851–880

Read EK, O'Rourke M, Hong GS, Hanson PC, Winslow LA, Crowley S, Brewer CA, Weathers KC (2016) Building the team for team science. Ecosphere 7(3):e01291. https://doi.org/10.1002/ecs2.1291

Rittel HW, Webber MM (1973) Dilemmas in a general theory of planning. Policy Sci 4(2):155–169

Rockwell SK, Kohn H (1989) Post-then-pre evaluation. J Ext 27(2):144–150

Salas E, Reyes DL, McDaniel SH (2018) The science of teamwork: progress, reflections, and the road ahead. Am Psychol 73(4):593–600

Salazar MR, Lant TK, Fiore SM, Salas E (2012) Facilitating innovation in diverse science teams through integrative capacity. Small Group Res 43(5):527–558

Sandoval WA (2014) Conjecture mapping: an approach to systematic educational design research. J Learn Sci 23:18–36

Shew A (2018) Workshop: interdisciplinary science, economic development, and sustainability in southern Africa: navigating complex human-environmental problems in diverse teams and challenging settings. A Participatory Workshop for the Swaziland Economic Policy Analysis and Research Center

Spranger E (1928) Reprinted types of men (target training international 2013) with introduction by bill Bonnstetter and epilogue by Ron Bonnstetter. ISBN: 978-0970753137

Stokols D (2014) Training the next generation of transdisciplinarians. In MO O'Rourke, S Crowley, SD Eigenbrode, & JD Wulfhorst (Eds.) Enhancing communications & collaboration in interdisciplinary research. Los Angeles, CA: Sage Publications

Stokols D, Hall KL, Taulor BK, Moser RP (2008) The science of team science overview of the field and introduction to the supplement. Am J Prev Med 35(2S):S77–S89

Soranno PA, Schimel DS (2014) Macrosystems ecology: big data, big ecology. Front Ecol Environ 12:3

Star S, Griesemer J (1989) Institutional ecology, 'translations' and boundary objects: amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39. Soc Stud Sci 19 (3): 387–420. doi: https://doi.org/10.1177/030631289019003001

Thompson K, Danielson A, Gosselin DC, 7 others (2017) Designing the EMBeRS summer school: connecting stakeholders in learning, teaching and research. In: Chen W et al (eds) Proceedings of the 25th international conference on computers in education. Asia-Pacific Society for Computers in Education, Christchurch, pp 210–215

Thompson K, Gouvea J, Habron G (2016) A design approach to understanding the activity of learners undertaking a model based reasoning course: environment and diversity. The International Conference of the Learning Sciences, Singapore

TTI Success Insights (TTIS) (2012) TTI technical reports compendium. (TTISI 2012) (https://imagesttiresearchcom/wp-content/uploads/2019/05/02094711/tech_report_compendiumpdf Last Viewed August 1, 2019

Vogler JS, Thompson P, Davis DW, Mayfield BE, Finley PM, Yasseri D (2018) The hard work of soft skills: augmenting the project-based learning experience with interdisciplinary teamwork. Instr Sci 46(3): 457–488

Voogt J, Pareja Roblin N (2012) A comparative analysis of international frameworks for 21st century competences: implications for national curriculum policies. J Curric Stud 44(3):299–321

Weik A, Withycombe L, Redman CL (2011) Key competencies in sustainability: a reference framework for academic program development. Sustain Sci. https://doi.org/10.1007/s11625-011-0132-6

Weik A, Berstein MJ, Rider FRW, Cohen M, Forrest N, Kuzdas C, Kay B, Keeler LW (2015) Operationalizing competencies in higher education for sustainable development. In: Barth M, Michelsen G, Rieckmann M, Thomas I (eds) Handbook of higher education for sustainable development, Chapter, vol 16, pp 241–260

Zemsky R (2009) Making reform work. Rutgers University Press, Piscataway