



## OPEN ACCESS

## EDITED BY

Patsie Polly,  
University of New South Wales, Australia

## REVIEWED BY

Crystal Chambers,  
East Carolina University, United States  
Miha Slapničar,  
University of Ljubljana, Slovenia

## \*CORRESPONDENCE

David Hanauer  
✉ hanauer@pitt.edu  
Viknesh Sivanathan  
✉ sivanathanv@hhmi.org

RECEIVED 01 June 2024

ACCEPTED 26 July 2024

PUBLISHED 24 October 2024

## CITATION

Hanauer D, Alvey R, An P, Bancroft C, Butela K, Coleman S, Clase KL, Collins P, Conant S, Connerly P, Connors B, Dennis MK, Doyle EL, Edwards D, Fillman C, Findley A, Frost VJ, Gainey M, Golebiewska U, Guild N, Gusky SB, Johnson A, Johnson K, Klyczek KK, Lee-Soety J, Lindberg H, Mastropaolo MD, Merkle JA, Mitchell J, Molloy S, Nieto F, Nissen J, Perez Morales T, Peters NT, Pfeifer SP, Pollenz R, Preuss ML, Rosas-Acosta G, Saha MS, Sprenkle A, Sunnen CN, Tobiason D, Tolsma SS, Ware V, Ahumada-Santos YP, Alvarez RV, Anderson J, Ayuk M, Báez-Flores ME, Bailey D, Baliraine F, Behr E, Beyer AR, Bhalla S, Bono LM, Breakwell DP, Byrum C, Duffy I, Gleichsner A, Harrison M, Ho R, Hughes LE, Kagey JD, Kohl K, McClory S, Moyer A, Mussi MA, Nance H, Nsa IY, Page ST, Parra Unda JR, Rocheleau J, Swerdlow S, Thoemke K, Valentine MS, Vega QC, Ward C, Williams DC, Wisner E, Biederman WH, Cresawn SG, Graham MJ, Hatfull G, Heller D, Jacobs-Sera D, Monti D, Ramakrishna P, Russell D and Sivanathan V (2024) The professional identity of STEM faculty as instructors of course-based research experiences. *Front. Educ.* 9:1442306. doi: 10.3389/educ.2024.1442306

# The professional identity of STEM faculty as instructors of course-based research experiences

David Hanauer<sup>1\*</sup>, Richard Alvey<sup>2</sup>, Ping An<sup>3</sup>, Christa Bancroft<sup>4</sup>, Kristen Butela<sup>3</sup>, Sean Coleman<sup>5</sup>, Kari L. Clase<sup>6</sup>, Parks Collins<sup>7</sup>, Stephanie Conant<sup>8</sup>, Pamela Connerly<sup>9</sup>, Bernadette Connors<sup>10</sup>, Megan K. Dennis<sup>11</sup>, Erin L. Doyle<sup>12</sup>, Dustin Edwards<sup>13</sup>, Christy Fillman<sup>14</sup>, Ann Findley<sup>15</sup>, Victoria J. Frost<sup>16</sup>, Maria Gainey<sup>17</sup>, Urszula Golebiewska<sup>18</sup>, Nancy Guild<sup>14</sup>, Sharon B. Gusky<sup>19</sup>, Allison Johnson<sup>20</sup>, Kristen Johnson<sup>21</sup>, Karen K. Klyczek<sup>22</sup>, Julia Lee-Soety<sup>23</sup>, Heather Lindberg<sup>24</sup>, Matthew D. Mastropaolo<sup>25</sup>, Julie A. Merkle<sup>26</sup>, Jon Mitchell<sup>27</sup>, Sally Molloy<sup>28</sup>, Fernando Nieto<sup>29</sup>, Jillian Nissen<sup>29</sup>, Tiara Perez Morales<sup>30</sup>, Nick T. Peters<sup>31</sup>, Susanne P. Pfeifer<sup>32</sup>, Richard Pollenz<sup>33</sup>, Mary L. Preuss<sup>34</sup>, Germán Rosas-Acosta<sup>35</sup>, Margaret S. Saha<sup>36</sup>, Amy Sprenkle<sup>37</sup>, C. Nicole Sunnen<sup>23</sup>, Deborah Tobiason<sup>38</sup>, Sara S. Tolsma<sup>39</sup>, Vassie Ware<sup>40</sup>, Yesmi Patricia Ahumada-Santos<sup>41</sup>, Regina V. Alvarez<sup>10</sup>, Justin Anderson<sup>42</sup>, Mary Ayuk<sup>43</sup>, María Elena Báez-Flores<sup>41</sup>, Dondra Bailey<sup>44</sup>, Frederick Baliraine<sup>45</sup>, Elizabeth Behr<sup>46</sup>, Andrea R. Beyer<sup>47</sup>, Suparna Bhalla<sup>48</sup>, Lisa M. Bono<sup>49</sup>, Donald P. Breakwell<sup>50</sup>, Christine Byrum<sup>51</sup>, Iain Duffy<sup>52</sup>, Alyssa Gleichsner<sup>53</sup>, Melinda Harrison<sup>54</sup>, Renee Ho<sup>3</sup>, Lee E. Hughes<sup>55</sup>, Jacob D. Kagey<sup>8</sup>, Kathryn Kohl<sup>16</sup>, Sean McClory<sup>56</sup>, Alison Moyer<sup>57</sup>, Maria A. Mussi<sup>58</sup>, Holly Nance<sup>59</sup>, Imade Y. Nsa<sup>60</sup>, Shallee T. Page<sup>61</sup>, Jesús Ricardo Parra Unda<sup>41</sup>, Jessica Rocheleau<sup>62</sup>, Sarah Swerdlow<sup>3</sup>, Kara Thoemke<sup>63</sup>, Megan S. Valentine<sup>53</sup>, Quinn C. Vega<sup>64</sup>, Catherine Ward<sup>65</sup>, Daniel C. Williams<sup>66</sup>, Ellen Wisner<sup>67</sup>, William H. Biederman<sup>68</sup>, Steven G. Cresawn<sup>69</sup>, Mark J. Graham<sup>70</sup>, Graham Hatfull<sup>3</sup>, Danielle Heller<sup>68</sup>, Deborah Jacobs-Sera<sup>3</sup>, Denise Monti<sup>71</sup>, Pushpa Ramakrishna<sup>68</sup>, Daniel Russell<sup>3</sup> and Viknesh Sivanathan<sup>68\*</sup>

<sup>1</sup>Department of English, Indiana University of Pennsylvania, Indiana, IN, United States, <sup>2</sup>Biology, Illinois Wesleyan University, Bloomington, IN, United States, <sup>3</sup>Department of Biological Sciences, University of Pittsburgh, Pittsburgh, PA, United States, <sup>4</sup>Biological Sciences, University of Southern California, Los Angeles, CA, United States, <sup>5</sup>Biology, Wartburg College, Waverly, IA, United States, <sup>6</sup>Agricultural and Biological Engineering, Purdue University, West Lafayette, IN, United States, <sup>7</sup>Natural Sciences, Mitchell Community College, Statesville, NC, United States, <sup>8</sup>Department of Biology, University of Detroit Mercy, Detroit, MI, United States, <sup>9</sup>School of Natural Sciences, Indiana University Southeast, New Albany, IN, United States, <sup>10</sup>Science, Dominican University New York, Orangeburg, NY, United States, <sup>11</sup>Biology, Marist College, Poughkeepsie, NY, United States, <sup>12</sup>Department of Biology, Doane University, Crete, NE, United States, <sup>13</sup>Biological Sciences, Tarleton State University, Stephenville, TX, United States, <sup>14</sup>Molecular, Cellular, and Developmental Biology University of Colorado Boulder,

Boulder, CO, United States,<sup>15</sup>Biology - School of Sciences, University of Louisiana at Monroe, Monroe, LA, United States,<sup>16</sup>Biology, Winthrop University, Rock Hill, SC, United States,<sup>17</sup>Chemistry and Physics, Western Carolina University, Cullowhee, NC, United States,<sup>18</sup>Biological Sciences and Geology, Queensborough Community College, CUNY, New York, NY, United States,<sup>19</sup>STEM, Northwestern Connecticut Community College, Winsted, CT, United States,<sup>20</sup>Center for Biological Data Science, Virginia Commonwealth University, Richmond, VA, United States,<sup>21</sup>Department of Life Sciences, University of New Hampshire at Manchester, Manchester, NH, United States,<sup>22</sup>Biology Department, University of Wisconsin–River Falls, River Falls, WI, United States,<sup>23</sup>Department of Biology, Saint Joseph's University, Philadelphia, PA, United States,<sup>24</sup>Biology, Virginia Western Community College, Roanoke, VA, United States,<sup>25</sup>Sciences, Neumann University, Aston, PA, United States,<sup>26</sup>Department of Biology, University of Evansville, Evansville, IN, United States,<sup>27</sup>Science and Mathematics, Northern State University, Aberdeen, SD, United States,<sup>28</sup>Molecular and Biomedical Sciences, University of Maine, Orono, ME, United States,<sup>29</sup>Biological Sciences, State University of New York at Old Westbury, Old Westbury, NY, United States,<sup>30</sup>Biological Sciences, Benedictine University, Lisle, IL, United States,<sup>31</sup>Plant Pathology, Entomology, and Microbiology, Iowa State University, Ames, IA, United States,<sup>32</sup>Center for Evolution and Medicine, School of Life Sciences, Arizona State University, Tempe, AZ, United States,<sup>33</sup>Molecular Biosciences, University of South Florida, Tampa, FL, United States,<sup>34</sup>Natural Sciences and Mathematics, Webster University, St. Louis, MO, United States,<sup>35</sup>Biological Sciences, The University of Texas at El Paso, El Paso, TX, United States,<sup>36</sup>Biology, College of William & Mary, Williamsburg, VA, United States,<sup>37</sup>Biology, Salem State University, Salem, OR, United States,<sup>38</sup>Biology, Carthage College, Kenosha, WI, United States,<sup>39</sup>Department of Biology, Northwestern College, Orange City, IA, United States,<sup>40</sup>Biological Sciences, Lehigh University, Bethlehem, PA, United States,<sup>41</sup>Unidad de Investigaciones en Salud Pública, Facultad de Ciencias Químico Biológicas, Autonomous University of Sinaloa, Culiacán, Mexico,<sup>42</sup>Department of Biological Sciences, Southeastern Louisiana University, Hammond, IN, United States,<sup>43</sup>Biology, Howard University, Washington, DC, United States,<sup>44</sup>Department of Natural Sciences, Coppin State University, Baltimore, MD, United States,<sup>45</sup>Biology & Kinesiology, LeTourneau University, Longview, TX, United States,<sup>46</sup>Biology, Madison Area Technical College, Madison, SD, United States,<sup>47</sup>Department of Biology, Virginia State University, Petersburg, VA, United States,<sup>48</sup>Natural Science, Mount Saint Mary College, Newburgh, NY, United States,<sup>49</sup>Department of Biological Sciences, Texas Tech University, Lubbock, TX, United States,<sup>50</sup>Microbiology and Molecular Biology, Brigham Young University, Provo, UT, United States,<sup>51</sup>Department of Biology, College of Charleston, Charleston, SC, United States,<sup>52</sup>Department of Natural Sciences, Saint Leo University, St. Leo, FL, United States,<sup>53</sup>Biological Sciences, SUNY Plattsburgh, Plattsburgh, NY, United States,<sup>54</sup>Science Department, Cabrini College, Radnor, PA, United States,<sup>55</sup>Department of Biological Sciences, University of North Texas, Denton, TX, United States,<sup>56</sup>Natural Sciences Department, La Salle University, Philadelphia, PA, United States,<sup>57</sup>Department of Biology, Drexel University, Philadelphia, PA, United States,<sup>58</sup>Departamento de Microbiología Básica, Facultad de Ciencias Bioquímicas y Farmacéuticas-UNR, Rosario, Argentina,<sup>59</sup>Natural Sciences, College of Coastal Georgia, Brunswick, GA, United States,<sup>60</sup>Microbiology, University of Lagos, Lagos, Nigeria,<sup>61</sup>College of Health and Natural Sciences, Franklin Pierce University, Rindge, NH, United States,<sup>62</sup>Biology, University of Massachusetts Amherst, Amherst, MA, United States,<sup>63</sup>Biology, The College of St. Scholastica, Duluth, MN, United States,<sup>64</sup>Biology, Montclair State University, Montclair, NJ, United States,<sup>65</sup>Biological Sciences, Durham Technical Community College, Durham, NC, United States,<sup>66</sup>Biology, Coastal Carolina University, Conway, AR, United States,<sup>67</sup>Biological Sciences, University of North Carolina at Charlotte, Charlotte, NC, United States,<sup>68</sup>Center for the Advancement of Science Leadership and Culture, Howard Hughes Medical Institute, Chevy Chase, MD, United States,<sup>69</sup>Department of Biology, James Madison University, Harrisonburg, VA, United States,<sup>70</sup>Department of Ecology and Evolutionary Biology, Yale University, New Haven, CT, United States,<sup>71</sup>Hicks Honors College, University of North Florida, Jacksonville, FL, United States

The professional identity of scientists has historically been cultivated to value research over teaching, which can undermine initiatives that aim to reform science education. Course-Based Research Experiences (CRE) and the inclusive Research and Education Communities (iREC) are two successful and impactful reform efforts that integrate research and teaching. The aim of this study is to explicate the professional identity of instructors who implement a CRE within an established iREC and to explore how this identity contributes to the success of these programs. 97 CRE instructors from the Science Education Alliance (SEA) iREC participated in a 2-year, multi-stage, qualitative research project that involved weekly reflective journaling, autoethnographic description, small group evaluation and writing, and large-scale community checking. The resulting description of professional identity consisted of shared *values* (inclusivity, student success, community membership, ownership/agency, science, overcoming failure, and persistence), specified *roles* (mentor, advocate, scientist, educator, motivator, collaborator, community builder, learner, evaluator and project manager) and a stated *sense of self* (dedicated, resilient, pride in students, multiskilled, valued, community member, responsible and overworked). Analysis of individual reflective diary entries revealed how a professional identity underpinned and facilitated the ways in which faculty addressed challenges that arose and worked toward the success of every student. It is the self-concept of the professional identity of the instructor in the context of the CRE classroom that directed the extended commitment and effort that these

instructors evidently put into their work with students, which facilitated student engagement, student persistence, and their collective scientific output. The study concludes that a professional identity of STEM faculty in the context of a CRE and iREC combines being a researcher and educator, and that this integrated identity is central for current initiatives aimed at transforming undergraduate STEM education.

#### KEYWORDS

inclusive research and education community, Science Education Alliance, course-based research experience, STEM faculty professional identity, undergraduate science education

## Introduction

Longstanding calls for transformation in undergraduate science education highlight the inertia of change at a national level (Brewer and Smith, 2011; President's Council of Advisors on Science and Technology (PCAST), 2012). Brownell and Tanner (2012) raise as a key factor undermining transformation efforts in STEM the professional identity of STEM faculty, which has historically been cultivated to value research over teaching and which has created tension between these two roles of STEM faculty. Over the last decade and a half, two broadly adopted, highly impactful and related curricular reform efforts in STEM, namely Course-based Research Experiences (CREs) and the inclusive Research and Education Community (iREC), have integrated research and teaching and may thus operate in a manner that resolves the tension between the two aspects STEM faculty identity, if not synergizes them (Graham et al., 2013; Auchincloss et al., 2014; Rodenbusch et al., 2016; Hanauer et al., 2017, 2022a; Monti et al., 2024). Here, we explicate the professional identity of STEM faculty who are engaged in a CRE and iREC and explore how that identity shapes the outcomes of these reform efforts.

CREs are designed to scale up access for undergraduate students to hands-on research experiences that promote their learning and persistence in STEM. By placing research in typical undergraduate laboratory courses (e.g., introductory biology laboratory courses), CREs enable students to readily access authentic research experiences. Over a decade of assessments have made clear that through a CRE, students develop a sense of ownership over their research, agency in their learning, and science identity that together increases their desire and likelihood to remain in the sciences (Russell et al., 2007; Jordan et al., 2014; Hanauer et al., 2017; Hernandez et al., 2018; Hanauer et al., 2022a). Importantly, these outcomes are observed for students from a wide range of demographics. Recent studies exploring the ways in which these student outcomes emerge highlight a central role of CRE pedagogy. In particular, there is a rich suite of conceptual and emotional facilitation by the instructor ranging from modeling scientific thinking to promoting independence and perseverance, all of which takes place across multiple levels, from large group settings to small peer groups and individual one-on-one engagement (Hanauer et al., 2022b). There is also extensive usage of *ad-hoc*, informal, ungraded formative assessment that is facilitative of student learning (Hanauer et al., 2023). These studies make clear that in a CRE, STEM faculty are functioning in ways that go beyond the usual instructional practices in traditional undergraduate laboratory courses to also assume the role of mentors more typical in academic research laboratory settings.

iRECs were developed to support broad adoption of CRE teaching by STEM faculty. Through an iREC, STEM faculty are provided both pedagogical and research support to lead a CRE and are coordinated

as a community that convenes regularly to share and advance their research and pedagogy (Monti et al., submitted). The Science Education Alliance (SEA) by the Howard Hughes Medical Institute (HHMI), Genomics Education Partnership, and Tiny Earth are three well-established iRECs that each support large communities of STEM faculty at dozens or hundreds of colleges and universities (Shaffer et al., 2010; Jordan et al., 2014; Elgin et al., 2017; Hanauer et al., 2017; Hurley et al., 2021).

For these STEM faculty who lead a CRE and supported to do so within the context of an iREC, research and teaching are integrated into a single entity, both within and beyond their classroom (Auchincloss et al., 2014; Hanauer et al., 2017). Accordingly, the professional identity of these STEM faculty may involve interesting developments in terms of how they see their roles as researchers and educators, which can shape their motivation and pedagogy, the resulting educational experience and outcomes for their students, as well as the overall success of CRE and iREC as STEM reform efforts. To better understand this positioning, the current study aims to explicate the professional identity of these undergraduate STEM faculty in the context of their CRE classroom and explore the relationship between this identity and student outcomes.

## What is professional identity?

Social theory has proposed that people that are together in a social setting develop a shared discourse which defines how they experience themselves (Bourdieu, 1993; Gee, 2002). Through conscious and unconscious social processes this shared discourse integrates, among other components, a series of values, beliefs, roles, aims and social understandings into an identity which constructs the individual's positioning in that social group (Lundell and Collins, 2001; Hodkinson and Hodkinson, 2004). On its simplest level, the professional identity of an instructor relates to a collective set of norms, beliefs, roles and practices which a social grouping within a higher education setting has developed (Kuh and Whitt, 1986; Kogan, 2000; Beijaard et al., 2004; Rhoades, 2007). For college level instructors, these collective identities may have emerged from prior education, exposure to disciplinary discourse, shared experiences within an institution, department or program and explicit position statements for any or all these groups (Kuh and Whitt, 1986; Mendoza, 2007). From all these different sources, professional identities may overlap and are subject to change and development over time (Rhoades, 2007). These identities may also come into conflict with one another forcing the instructor to navigate between different ways of self-positioning (Ibarra and Obodaru, 2016).

Prior research has examined various aspects of instructors' professional identities. These include investigations into how instructors understand their professional commitments and responsibilities (Wallenburg et al., 2016; Nadelson et al., 2017; Shahabi et al., 2020), the

aims of their profession and discipline (Hancock and Walsh, 2014; D'Arcy et al., 2019), the experiences and ways of being in their professional roles (Wald et al., 2018; Cameron et al., 2020; O'Leary and Cantillon, 2020), and the values associated with their work (Hancock and Walsh, 2014; D'Arcy et al., 2019). Overall, as argued by Raste and Murthy (2024) a teacher's professional identity reflects the way a person perceives themselves within the educational setting within which they are working. This professional identity has direct ramifications on the way the person functions and interacts in the pedagogical work and the outcomes for themselves and their students. A professional identity addresses the beliefs, values, roles, commitments and aims of a teacher in a particular educational setting (Beijaard et al., 2004).

Research has also shown that the professional identities of science teachers is different from teachers of other disciplines, and that this identity can differ based on various social contextual factors such as institution, science discipline, program and type of employment, and the degree of support and collegial interaction they experience (Rodrigues and Mogarro, 2019; Feser and Haak, 2023). Reflecting Lave and Wenger's (1991) situated learning theory and Wenger's (1998) communities of practice (CoP) model, Chen and Mensah (2022) considered the way in which science teachers integrate aspects of the cultural practices of the communities they belong to into their professional identities. Values, roles, educational attitudes, and behaviors concerning science teachers' professional identities are acquired and learnt within professional contexts (Pérez Gracia et al., 2019; Shwartz and Dori, 2020). Basically, as predicted by both Lave and Wenger's (1991) and Wenger's (1998) theoretical position on how personal development occurs, participation in an active community of practice facilitates instructor professional identity construction without explicit instruction taking place; it is the participation in the community which directs these identity developments.

In the current study, all STEM faculty who participated were drawn from the SEA iREC and implement the Phage Hunters Advancing Genomics and Evolutionary Science (SEA-PHAGES) CRE project (Hanauer et al., 2017). The iREC has a particular series of features that are important in relation to the developmental aspects of a shared professional identity (Monti et al., 2024). First, an iREC has a well-defined mission of supporting STEM faculty to provide each student with a high-quality educational research experience as means to promote their learning and the persistence, *en masse* and across diverse student demographics (Hanauer et al., 2017). Second, the iREC structure and curriculum provides instructors with recurring opportunities to leverage one another to advance their science and pedagogy. This is accomplished through a centralized scientific and administrative structure that facilitates extensive and continual interactions over the long-term between faculty who are situated in multiple institutions across the US (Hanauer et al., 2017). With the program's underpinning CRE curriculum being similar for all faculty, there is clear basis for conversation and collaboration in relation to their research and teaching. In line with theories of identity development within Communities of Practice (Wenger, 1998), shared mission, participation, identification, extended engagement with other members of the community should be conducive to the development of a shared professional identity.

## Research questions

As reviewed above, the professional identity of an instructor has a role in how they conduct their pedagogical work. To date, there has not

been a study of the professional identity of instructors who lead CREs. Based on prior research there is reason to believe that instructors have a particular professional identity in a CRE setting that informs and directs their pedagogical practice. The current study aims to explicate the professional identity of instructors in a CRE classroom and explore how this may facilitate positive educational outcomes for their students. The current study was directed by two research questions:

- 1 What characterizes the professional identity of instructors in the context of a CRE?
- 2 What is the relationship between the professional identity of a CRE instructor, their pedagogy, and student outcomes?

## Methodology

### Overall design and research stages

The investigation of professional identity and the way this interacts with inclusive STEM education is complex. In order to avoid oversimplifying aspects of professional identity and the ways in which this identity might interact with the CRE instructors pedagogical work, a 2-year, multi-stage, qualitative research methodology involving a large number of CRE instructors was conducted. The data collection process integrated weekly reflective journaling, autoethnographic description, small group evaluation and writing, and large-scale community checking. Table 1 presents the stages of the project, the process of data collection and the data that is elicited at each stage.

### Participants

The participants for this study consisted of 97 CRE instructors drawn from the HHMI SEA program. Table 2 summarizes the demographic data collected from the CRE instructors who participated in this study. As can be seen in the table, the majority of respondents were women, were faculty who had tenure, and were faculty with full-time positions at the Associate or Full Professor levels. However, there was also representation of non-tenured faculty with other rankings. Ethnographic data was not collected from participating faculty. All data was collected according to the ethical guidelines of Indiana University of Pennsylvania, IRB #21-107.

### Instruments

This study involved multiple stages of data collection. Each stage involved its own instructions. The full prompts for the following stages can be found in Supplementary Appendix A: A. Weekly Reflective Journal Prompt; B. Autoethnographic Writing Workshop Prompts; C. Small Group Evaluation and Writing Prompts; D. Individual Identity Differentiation Writing Prompts; E. Community Checking and Validation Prompts following Presented Analysis; & F. Community Explication of the Manifestation of Inclusive Education in CRE Instruction.

### Procedure

The process of data collection for this project lasted for 2 years. The first year of work was conducted by the faculty individually in which they completed a weekly reflection on their teaching in a CRE. The individual entries were not monitored. However, every month a short survey was sent to faculty asking about the number of weeks of entries had been completed. Following the first year of reflective journal writing, two workshops were held with faculty. The first of these



TABLE 1 Overview of the data collection process and resultant data.

Data collection stage	Process description	Resultant data
Reflective journaling	For a year, 97 CRE faculty wrote weekly reflections in a provided dedicated journal on meaningful events that happened during their week of teaching	A <i>reflective journal</i> with weekly entries and comments on notable teaching experiences with students. On average participants had 18 weeks of reflective comments on their teaching
Autoethnographic writing	Following the completion of the year of reflective writing, an online Zoom writing workshop was held with 46 CRE faculty. Each instructor read through their reflective journals and chose 3 of their entries that in their opinion represented their work and interaction with their students as a CRE instructor. Following this they wrote a description of their professional identities as CRE instructors.	A series of 3 <i>weekly journal entries</i> considered characteristic of the instructors work as a CRE instructor and a <i>written description of their professional identities</i> .
Small group evaluation and writing	A second writing workshop was held in which faculty who participated in the first workshop shared their professional identity descriptions with a small group of other faculty. The CRE instructors were tasked to define their collective professional identity	A collection of written descriptions of <i>shared professional identity</i>
Individual identity differentiation	The final part of the workshop in which a shared professional identity was defined, faculty were asked to think of ways in which they differ from the shared identity. Faculty were asked to specify points at which their personal identities differed from the group identity. Following the workshop, the written descriptions of individual faculty identities were submitted.	A collection of <i>written descriptions of individual faculty identities</i> interacted with the specified shared professional identity.
Community checking and validation	Once the data had been analyzed, it was presented to over 100 faculty at an annual meeting of CRE instructors. The analyzed data for the definition of the professional identity of a CRE instructor was presented and discussed by small groups of instructors. A survey was presented to faculty to assess the quality of the data and to make revisions and modifications to the presented categories and analyses.	A survey summarizing the <i>degree of agreement with presented analyses</i> and <i>recommendations for modification</i> or revision.
Community explication of inclusive CRE instruction vignettes	A final meeting was held with a large group of instructors to explicate the ways in which CRE instruction may manifest aspects of inclusive educational practices. In small groups faculty were presented with specific entries from the year-long diary study chosen for their relevance. Each vignette was discussed in a small group and following the session each instructor completed a survey in which they presented their understandings.	A list of written explications of the way in which specific instructors understand how inclusive education is manifest in CRE instruction

workshops directed faculty to read their complete reflective journals, choose 3 items and write a position on their understanding of their professional identity. The second workshop involved faculty hearing each other's experiences in a small group format and defining a shared definition of professional identity and ways in which each person differed from this shared identity. The list of three chosen journal entries, the shared definition of professional identity and the individual divergence from that shared identity were all submitted as data to the lead researcher of this project. The data was analyzed and modeled in order to see the shared components of a professional identity. The resultant analyses and models were presented to a large group of faculty ( $n = 100 +$ ) in order to check the validity of the analyses, categories and models. This member checking process was held at an annual faculty symposium. Faculty considered each of the components of the analysis in a small group format and then following the symposium submitted their agreements, changes and modifications in an online survey. The final process of data collection involved presenting entries from the journal study which related to the concept of inclusive education to the faculty member for their explication and interpretation. In small groups CRE instructors discuss the entries and following the session each instructor completed a survey providing their interpretation of how inclusive education is manifest in CRE pedagogy.

## Analysis

As a result of the nature of the data which involved year-long reflective diary entries and considerations of personal and

professional identity, a process of analysis which directly involved faculty was utilized. This investigation combined collective autoethnographic approaches (Chang et al., 2013) in which participants are also analysts of their own data with more traditional content analysis approaches (Krippendorff, 1980) to resultant written products. Through prompted individual reflection and small group discussion, faculty chose and defined their own and the shared definition of professional identity. Small group discussion between 3 or 4 faculty involved presenting and debating the features of professional identity. Group discussion was designed to allow a provisional shared and agreed upon view of professional identity to emerge. As described below a second stage of validation of these definitions of professional identity was conducted with a large group of faculty. These processes of analysis and writing produced 3 different written products: a list of 3 explicated experiences from their reflective journals, a statement from each small group on the definition of their shared professional identities and a written statement of their personal identities as CRE instructors.

The submitted written data was analyzed using a content analysis approach. Initially the shared descriptions of professional identity were read by two applied linguistic researchers and a list of general categories for the specification of a shared professional identity were proposed. This process specified three general categories of utterances: (1) The *roles* a CRE instructor may take on; (2) The values a CRE instructor believes in; & (3) The sense of self a CRE instructor may have. Following the specification of these general categories, the

TABLE 2 Demographic features of faculty participants.

		N	%
Rank	Full professor	31	32.6
	Associate professor	26	27.4
	Assistant professor	19	20.0
	Clinical (non-tenure) professor	1	1.1
	Instructor	1	1.1
	Graduate teacher assistant	5	5.3
	Other		
Teaching position	Full time	85	88.5
	Part time	11	11.5
Gender identification	Woman	65	68.4
	Man	28	29.5
	Unlisted	2	2.1
Tenure status	Tenured	57	60.0
	Not-tenured	38	40.0

specific subcategories of the faculty utterances were defined. For each of these three, a list of specific roles, values and sense of self were defined.

In order to check the specified general categories and subcategories, the full set of explicated reflective journal experiences was read for additional specification of the roles, values and sense of self of professional identity. The aim was to understand the source and the experiences which underpinned each of the categories and subcategories of professional identity. If a specified sub-category could not be substantiated with at least one described experience, it was removed from the list of subcategories. If a role, value or sense of self that had not been specified in the general statements of professional identity but was found to be present in at least three specific experiences it was added to the lists of subcategories. A list of general categories, subcategories, and an overall model of professional identity was defined. The full dataset of reflective data entries was specified according to the model and exemplars which manifest the features of the category and subcategory were chosen through discussion.

The results of the content analysis approach were presented to a large group of instructors and each member provided feedback. This feedback consisted of (1) specification of agreement or disagreement with each category and subcategory; (2) proposals for changes and modifications; and (3) new items that needed to be added. The degree of agreement with the model was calculated as a simple percentage of participants stating agreement and proposed modifications and additional were evaluated.

The final analysis related to the explication of the ways in which inclusive education is manifest in CRE instruction. The full set of journal entries was reviewed and entries were categorized according to types of inclusive educational action. All entries were read but not all entries were found to be relevant for the theme of inclusive education. Once the entries had been categorized according to different aspects of inclusive education, representative entries that most accurately represented the theme and offered the desired degree of detail were chosen. In some cases, two vignettes were considered for each theme. These were then discussed by three of the researchers. After this consultation, the faculty who wrote each of the entries were contacted to see if the interpretation was accurate and their willingness

TABLE 3 Definitions of general categories of professional identity and the percentage of overall community agreement.

General categories	Definition	Community agreement %
Values	The ways of behaving that a person considers important in their professional life	91.43
Roles	The different types of professional role an instructor has with all associated expectations and meanings.	88.58
Sense of self	The personal characteristics that are associated with being a CRE instructor	85.72

to highlight their specific diary contributions in the manuscript. As a final stage all the vignettes were presented all the faculty for their feedback. Once each instructor had submitted their interpretation of the journal entry vignettes, they were read and shared understandings summarized in relation to each vignette.

## Results

### Categories of professional identity

To establish general categories of professional identity, an initial analysis was conducted on the small-group, shared descriptions of professional identity. Table 3 presents the results of this analysis. The three general categories of values, roles and sense-of-self were defined in order to organize and analyze the written descriptions provided by the instructors in this study. While this general analytic frame emerged from the reading of the data, there is a rationale based on prior literature that underpins this approach. An analysis of the specific values involved in the professional identity of an instructor in the context of their CRE classroom provides insight into the beliefs that support the actions and decisions taken by each instructor in their pedagogical work. The shared values of a professional specify the aims and goals of these instructor and what they are trying to achieve. The list of roles specified in the small group discussions clarifies the functions and positions that these instructors utilize in order to complete their functions and aims as specified by the values they believe in. The last general category – sense of self – specifies the personal characteristics that instructors feel are part of their professional identities in the context of their CRE classroom.

### Instructor values

Instructor values refer to ways of behaving that a person considers important in their professional life. Table 4 presents the list of values specified by faculty in the descriptions of professional identity that were validated in their journal entries. Across the full set of values, a specific educational orientation emerges. These instructors are placing an emphasis on the success of all students as members of the scientific

TABLE 4 Specification of the values of CRE instructors with a definition, example statements and percentage of community agreement.

Specification	Definition	Example statements
CRE inclusivity	Behaving in a way that facilitates and supports that every student is treated fairly and equitably so that there is equal opportunity to conduct authentic research	"I conform in terms of the commitment to broadening undergraduate research education particularly among UR (underrepresented) groups who otherwise would not have access to a research experience."
Student success	The belief and set of behaviors that each student can meaningfully complete their authentic research experience successfully from a scientific, educational, and personal perspective.	"Additionally, all SEA-PHAGES faculty overwhelmingly share a passion for our students and their success, and are invested emotionally in this process. Student success, whether it be research success, content mastery, or some other desired outcome, is our success, too; we take great pride in our students and their work. I share in their joy and excitement every semester at the first appearance of plaques, encourage them when experiments fail, and admire their vast accomplishments when they present their scientific findings in posters or presentations."
Community membership	The belief and set of behaviors that make every student feel that they are a member of large scientific community dedicated to the production of shared scientific knowledge	"I think providing students an opportunity to build community and connections with each other and with me in a class/lab environment that is welcoming, comfortable, collaborative rather than competitive, and open is really important, especially for first-year students – a big part of my professional identity in these courses is tied to fostering this type of environment for students"
Ownership/agency	The belief and set of behaviors that see every student as an authentic researcher and learner who has control, ownership and agency over their research and education	"I think the best part of teaching is seeing that students can take what they have learned in introductory and other courses, put it together, and do it on their own in different contexts and produce a professional product."
Science	The belief and set of behaviors that the authentic research conducted by students in the lab is important to a wider community of scientists, may have value for solving real-world issues and can help us to understand of the world we live in.	"SEA-PHAGES faculty often treat students as scientific colleagues during the phage discovery process. In my own experience during the bioinformatics semester, we discovered an extremely unusual pattern of infection in which one phage seemed to infect an alternative host better than the original isolation host, and this difference was striking in terms of plaque morphology and titer. I was so excited to see these results when I looked in the incubator, and it was hard for me to avoid spoiling the results for students. I wanted to make sure that students "did the driving" in terms of interpreting these results, so I needed to tone down my level of excitement at the results until the class was able to reach conclusions together."
Overcoming failure	The belief and set of behaviors that see authentic scientific research as unpredictable and involving failure and that the role of the professional scientist is to learn from this and overcome presented challenges.	"students would be forced into difficult, uncomfortable situations where the results could not be predicted, and failures could sometimes not be explained. They had to be able to show the students the educational value of failure, in that their time was not wasted by repeating experiments but instead provided with a new avenue to learn, oftentimes more than if the experiments went perfectly."
Persistence	The belief and set of behaviors that support all students in continuing their educational path even though there are difficulties along the way.	"I'm deeply invested in helping students transition/acclimate to college-level learning and strongly believe that incorporating both authentic experiences in biology (i.e., phages) and metacognition into first-year courses can help students from broad backgrounds/levels of preparedness move through this often-challenging time."

Degree of community support: 91.43%.

community. To achieve these aims, instructors value promoting persistence, understanding and participation in the process of science, and ownership, agency and belonging in the community. These values highlight the importance faculty are placing on creating a positive and supportive educational environment. This suggests that faculty are prioritizing the success students, reflecting a deep commitment to their roles as educators and mentors. This focus on student success is a core component of their professional identity, highlighting their dedication to fostering an inclusive and supportive learning environment. This reinforces the sense that their role includes guiding students through challenges and further fostering a sense of ownership, enthusiasm and belonging in the scientific community. In the community checking process of the general category and the specific items on the values list, 91.43% of faculty agreed with these definitions and items.

## Instructor roles

Instructor roles refer to the various types of professional functions an instructor has, with all associated expectations and meanings. Table 5 presents the list of roles specified by the CRE instructors in this study. As can be seen these instructors see themselves as performing and providing a range of roles that together support and facilitate student learning, success and persistence within a CRE. Roles such as mentor, advocate, and motivator relate to the interpersonal interaction with the student to facilitate persistence. As seen in prior studies concerning how CRE instruction is conducted, these roles are crucial for helping students stay engaged through the challenges of authentic research. The roles of scientist, learner, collaborator, community builder and project manager are tied directly to the role of a lead researcher (i.e., a lab head). Faculty are working with students on

TABLE 5 Specification of the roles of CRE instructors with a definition, example statements and percentage of community agreement.

Specification	Definition	Example statements
Mentor	A role in which the instructor facilitates the development of a student researcher by providing advice, emotional support, personal training and feedback.	"The paragraph describes a committed teacher and a caring mentor. A mentor who motivates students and helps them grow. Person who has working knowledge of the science necessary to conduct the project and to run safely lab full of students."
Advocate and counselor	A role in which the instructor provides support and advice that help a student to overcome the barriers that emerge as a student researcher or as a student more broadly.	"One of my discussion colleagues noticed a thread through my responses is that I act like a coach and watch students work (individual or group) and step in only when they are struggling and need support."
Scientist	A role in which the instructor works and shares with student researchers their research practices, findings and communities in order to facilitate the furthering of scientific knowledge.	"I am a member of a community of scientists and educators who work collaboratively to seek insights into bacteriophage evolution and enhance STEM education."
Educator	A role in which the instructor uses their experience and knowledge of science and pedagogy to advance each student's knowledge, ability and disposition to complete their science education.	"We train students in a variety of laboratory and bioinformatic techniques and guide them as they analyze their results. As teachers, we teach scientific communication skills by having students document their work in a notebook and present their findings in written and oral forms."
Motivator	A role in which the instructor recognizes and announces the successes of students and encourages and inspires students during their research.	"I love that students think that I exude enthusiasm for the work they do in the lab and for the importance of their contributions to understanding aspects of phage biology."
Collaborator	A role in which the instructor works together with students for the shared aim of creating scientifically valuable output.	"Early in the semester I am the expert, and they are the learner, however, as the semester goes along, we are more colleagues working toward a common goal"
Community builder	A role in which the instructor creates for students a sense of community in the lab and with the broader community of scientists.	"I have always seen the main role of my course as building community, and my professional identity is mainly to facilitate the connections in this community."
Learner	A role in which the instructor learns new skills or knowledge in relation to science and educational issues	"The program provides opportunities for professional development in both scientific and education research, and therefore I have been able to continuously grow and learn in both areas."
Evaluator	A role in which the instructor assesses and evaluates both formally and informally the scientific work of the student researcher	"I use weekly reflection assignments to encourage students to relate phages and bacterial hosts to the topics discussed in the lecture portion. Having to correlate topics like photosynthesis to phages and bacteria can be challenging but moves the students away from memorization and to building connections. For example, I have had students' reflections relate photosynthesis to phages by discussing a journal article that they found about cyanobacteria phages."
Project Manager	A role in which the instructor oversees the development of the students' research projects and provides organizational support for the work being conducted.	"It is critical that SEA instructors are highly organized and well prepared for lab meetings, as it would be impossible to manage the many intersecting, complex protocols without these skills. However, as things will inevitably not work perfectly the first time and plans will change, they must also be highly adaptable, and have the confidence to manage those adaptations."

Degree of community support – 88.58%.

novel projects within the setting of a broader community of scientists who are all contributing to advancing science. As is typical in authentic research, the relations between the instructor and student are flattened in relation to some aspects of the work, with the faculty member and students learning together as the project develops. Finally, the roles of educator and evaluator are the more classic aspects of a teacher's role and remain a part of CRE teaching. Collectively, this set of roles shows the full gamut of what CRE teaching can involve, spanning those typical of both teachers and researchers. It is important to note that the range of roles that are included in the professional identity of a CRE instructor includes traditional roles such as being a mentor, educator and evaluator, psychosocial responsibilities such as counselor

and motivator and the roles of a working scientist such as collaborator, learner, project manager and community builder. This combination of roles reflects the complexity of the what teaching a CRE involves, which goes beyond the traditional concept of teaching.

## Instructor sense of self

Instructor sense of self refers to the personal qualities that instructors find relevant for their professional identity as an instructor in the context of their CRE classroom. The full list of items is presented in Table 6. The specific items reflect the challenges



TABLE 6 Specification of the sense of self of CRE instructors with a definition, example statements and percentage of community agreement.

Specification	Definition	Example statements
Dedicated	A sense of commitment, passion and persistence to help students and the scientific community as a whole to continue their shared research.	"To belong to a network of scientists with such passion for their work and dedication to their students is invigorating and inspiring."
Resilient and resourceful	A personal quality of the ability to respond in a variety of ways to novel situations and have the mental toughness to be able to contend with the unplanned outcomes and experiences of scientific research.	"My goal as a faculty is to be knowledgeable, confident in what I do and do not know, and flexible to be able to pivot or adapt to changing conditions."
Pride in students	The sense of personal satisfaction and accomplishment with student scientific and educational development and successes.	"I am >30 years into my career as a University Professor. I have never been involved in a program that has given me so much joy from the student perspective. To get to watch in real time the growth and development of these young scientists is a reason I get up in the morning and still put in 60 h a week. What I love doing in thinking up creative ways to make the challenge of research more approachable."
Multi-skilled	A personal quality of being able to function in a wide range of different roles required in order to manage a course-based research lab	"All of us are a jack of all trades, meaning that we do most all of the prep, teaching, grading and engagement of the course."
Valued	A sense that the educational and scientific work that the instructor performs is appreciated and respected by the students and broader scientific community.	"We are valued for what we bring to the community in both the education and scientific areas. There is shared ownership of discoveries."
Community member	The sense that one is a participating, contributing and valued member of a community of researchers.	"I strongly believe that I am functioning in an environment where I am on the same team with my students - we are in the research process together, neither of us knowing the outcome of the discoveries to unfold and all excited as we anticipate the next steps. I feel so comfortable within the community of SEA-PHAGES faculty"
Responsible	The personal quality in which the instructor feels accountable for the student's research and development.	"I feel a demanding sense of responsibility for student success, desiring to keep everyone engaged in the research process, and at times I blame myself when things go wrong."
Overworked	The sense that the work and responsibilities of an instructor in a CRE are extensive and can feel overwhelming.	"Stress and frustration was more apparent in earlier days in the semester, as I had to re-calibrate my expectations of students at this level and encourage them to be patient and accommodating to changes that were bound to come, and to encourage them to enjoy creativity, exploring the unknown, and to take reasonable risks in presenting their ideas about their experimental outcomes."

Degree of community support - 85.72%.

and opportunities that these instructors face in their professional work, such as adapting to diverse learners, managing multiple tasks, coping with stress, and collaborating with others. Importantly, this list indicates a set of attitudes and behaviors that are needed to support students in the uncertainties of engaging in authentic research, within a larger community of scientists. The need to be committed, flexible, creative, confident, and responsible underpins the qualities needed by instructors in order to function within the framework of a CRE and iREC. This sense of self is, in turn, leads to a sense of pride and self-value as an instructor, scientist and community member. It can also lead to the feeling of being overworked and overwhelmed with the cognitive, emotional and administrative load of courses of this type. Finally, it is interesting to note that in order to be able to function according to the roles and values of this professional identity, faculty see themselves as multi-skilled, resilient and flexible. Together this set of self-concepts can be seen as a response to actually performing the values and roles that characterize the professional identity of CRE instructors.

## CRE instructor professional identity, pedagogy, and student outcomes

As previously described, instructors in a CRE are functioning in ways that go beyond the usual instructional practices in traditional undergraduate laboratory courses to include the role of mentors more typical in academic research laboratory settings. In particular, instructors provide extensive conceptual and emotional support and *ad hoc*, informal feedback to their students in a CRE (Hanauer et al., 2022b, 2023). With the assumption that professional identity underpins the actions and decisions taken by instructors in their classrooms, then the shared values, roles, and sense of self for instructors in the context of a CRE that is revealed in this study offer a basis for understanding this rich pedagogy. If an instructor sees their role as a scientist, mentor and an educator, then their pedagogy will involve the types of facilitation that nurtures an appreciation for the rigor of science alongside the development of a passion for science. If their value system promotes inclusivity, belonging and student success, then they are going to act to promote engagement and learning for

every student. If they see themselves to be dedicated, resilient, valued and multiskilled, they are going to go beyond the usual parameters of what is expected for instruction in typical undergraduate STEM education.

These values, roles, and sense of self for instructors in the context of their CREs may also underlie the equitable outcomes observed for students across diverse demographics (Hanauer et al., 2017, 2022a). To explore the ways in which this professional identity manifest as inclusive education, that is actions and pedagogy by the instructor that promotes the success of *all* students engaged in a CRE, the full set of weekly reflections were analyzed by groups of instructors to exemplify diverse ways in which they were manifesting inclusive education in their CRE classroom. Four examples are presented below as vignettes from reflective diary entries.

### Vignette 1: Accommodating disability

"I found out today that I have a student who is deaf and will require special accommodations (interpreters and note-taker). I know I can do this in the lecture, but I am 100% sure I cannot do this in the SEA-PHAGES lab. We are masked--how do I deal with this? How do I have interpreters on the Zoom screen and still let the student do the work independently? How do I ensure she is safe? How much can her lab partners participate in this journey? How do I manage the lab to be sure she does not stand out from the group? I called her advisor and special services to figure out who put her in this class. As I think about it, I am excited. Maybe this is the spark she needs to figure out her passion. This is my job to help her use this experience to do just that!

*Thoughts:* At first, I found myself angry that the student was taking the course because she is not a biology major. This is a lot of work to set up the lab. It is my job to ensure equal access to science and these emotions are not in line with what you believe or are charged with. You state that you fully believe in equity and inclusion, and yet you feel this way. You better dig deep and find a way to make it work for the student, no matter the "amount of work" it takes on your part. You believe in the outcome, and you believe in education. You know this experience is good for the bio majors, so why not for her? Dig deep. It all worked out in the end- she passed, she persisted- she did not choose biology as a major, but it helped her FEEL successful as a student. She told her advisor she liked the class and me (was I worried she would not like me?). I know that I grew as an educator because of this experience."

This brief reflective diary entry provides an example of how inclusive education is put into practice by the instructor and how professional identity plays a role in this thought process. The presence of a deaf student in the lab raises serious concerns for the instructor. These include an increased workload, worries about the student's safety, and changes to the core design of authentic research practices like collaboration with peers. But the professional identity of the instructor in the context of their CRE classroom includes the belief in the importance of having a student find a "passion" for science and that the authentic research experience is the way to achieve this. Furthermore, clearly this instructor sees this as part of their position. The instructor connects this to the ideas and beliefs in inclusive education which then translated into a set of behaviors, supports and practices which allowed this student to be successful (and enjoyably) complete her research experience. In this reflective entry, inclusive education emerges from the professional identity of the instructor in the context of their CRE classroom, with the values, roles and sense of self that this entails.

### Vignette 2: Overcoming educational discrepancies

"I was once again surprised at how little my students understood about the nature of science at the beginning of the semester even though I had taught this many times before. But I knew I needed to really empathize with them and get into their frame of mind in order to teach effectively. The specific experience that triggered this feeling was how students said that they never saw a single piece of equipment in the room before and, even after doing the reading, had no idea about the process of science or research. One student asked "is this a science lab? Is this what they look like?" Our program takes only students from underserved backgrounds so this made me feel that we do have a very critical role in making these students feel like they belong - and that this is an uphill struggle sometimes. I re-felt this very strong feeling about the level of knowledge of these students (and how unfair our educational system is that would give some students strong backgrounds and other students virtually nothing). Even though my story was about one student, this was not a single experience - it was 15 students all expressing doubt and asking questions and being nervous about everything they saw in a "science Lab" and wondering how I was going to make them feel like they belonged in this environment. My emotion was "how am I going to get all 15 students from underserved backgrounds to become truly engaged in this process and understand and love what they are doing." But given that we successfully completed the year and now I know that half the class wanted to be a TA the following year so I now know it turned out OK. But still recall how daunting the feeling was - that I would never be able to engage them the way I wanted. I still feel this sense of "how do I make them love this and develop identity as scientists?" at the beginning of every year."

In this excerpt, the instructor reflects on the challenge of working with students who have very little if any of the expected scientific knowledge and experience prerequisites to complete a lab course. As seen in the excerpt very basic assumptions like knowing what a lab looks like were absent for some students who came into the instructor's CRE classroom. As expressed here the professional identity of the instructor includes values of student success, persistence, the role of building community and the deep desire to help these students to become scientists. Importantly the faculty member sees the lab setting within the broader construct of the way society constructs educational inequities and considers their classroom the setting which could help reverse such inequities. This aim goes beyond just addressing scientific knowledge and includes a sense of belonging and even love for science and research. The professional identity of the faculty member as a scientist and as an educator within a research community creates a conceptual framework that sees the educational backgrounds of the students not as a deficit and a precursor for failure, but rather as a significant societal task that needs to be and can be addressed through an authentic research experience.

### Vignette 3: Overcoming failure

"Approximately Week #3 into the Phage Discovery portion of the course, folks were having success in getting phage doing serial dilutions, picking a plaque...but one student was only getting empty plates. Just nothing. She was very frustrated. "Failure, Failure, Failure". However, she kept trying, not saying too much, coming in on off-times, both weekends of the semester...nothing. I would check her plates ahead of time. ...I even was doing isolation alongside and I would get plaques, but not her. Crappy sample? We even went back

to the sample bag and we even collected different samples. Still nothing. All the time...nothing...but her face was hard to look at. I could see her frustration; especially with her classmates moving forward in the isolation process. I felt terrible for her. She was not having a good experience, first semester in school, first in her family to go to college. I felt her pain and would often take her pain home with me, trying to develop a Plan B, Plan C. Plan D...to get her virus. One day, at the beginning of Week #4. ... I checked her plates and saw phage!! LOTs of them. It was also on *Gordonia* instead of the host most of the class was working with. I was so excited and simply could not wait until she came in to check her plates. She came in, went to the incubator, held her plates to the window as usual...expecting nothing again.... I watched her. She stood at the window longer than usual. She glanced around to I guess see if somebody was watching....then got her phone out to snap some photos. Then she came over to show me. She was positively glowing!! "It worked!! She said 'Finally, I have something positive to write in my lab data book.'" She then showed me the ones she wanted to pick and isolate further. I left her alone and about 1 min later, I came back to see how she was doing....she had not started. She was busy sending her mother the photo of her plaques. Apparently her mother had been asking, not understanding about phages or anything science, but she knew her daughter was worried about not getting virus and kept asking her how things were going. The student then asked if she could snap a selfie picture of the two of us with her plate of phages. Never had that happen before, but it was just the best! I felt relieved. Also, most happy. Together, we had made a wonderful day! Reflecting on that....I think the one-on-one attention, extra time off-class time and on the weekends...listening to Spotify while working in the lab, me showing her alongside helped. These are the times I enjoy being a teacher. Showing students one-on-one...it is how I learned and I was able to pass that on."

In this excerpt, the instructor presents a case of working as a mentor with one student who was struggling with her failure to find a phage and have a positive result to report. Several different actions were taken by the faculty member including devising different ways of achieving a positive result, mentoring the student one-on-one, working weekends and out of class with this student. What would motivate an instructor to go to these lengths to support student success? The instructor's professional identity and her core sense of dedication helps her to go way beyond usual lab practices. This instructor was working side by side with this student allowing her to continue and get past failure. The reward for the student in terms of a sense of ownership, confidence and just joy at science is evident in the description. What could have been an experience that led to the decision to leave STEM, was transformed into a moment of deep pride that needs to be shared with her family. The sense of closeness between the student and faculty member is clear and the value the instructor gets from this experience reinforces her dedication to her profession and why she instructs a CRE.

#### Vignette 4: Persistence through authentic science

"My third entry occurred in the middle of the second semester of bioinformatics. I have all the same students from the first semester plus a few more from a different section. This entry was about playing the long game with students, meaning the things we do to support students daily often do not come to fruition until much later. On this day I was assessing student annotations over spring break. Every single

student in my class had turned in annotations for all of their assigned genes. This was a remarkable moment that I celebrated because two of these students had had major difficulties in the first semester. They had plagiarized their final paper in the first semester, were dishonest at times, skipped classes and were overall unengaged. These students were also struggling in their other classes and were on university probation. But on that day, these students had completed their work on time and handed in high quality annotations with notes that demonstrated maximum effort. They had not missed any classes and when I reviewed attendance records at our daily mentoring program (for Phage students) they each had attended at least once weekly. They had also written in their learning journal how much they valued the support in [the daily mentoring program] when they felt intimidated on an assignment. These two students went on to play major roles in the writing of two of the MRA papers that we published this summer. I know that you cannot recruit every student to the mission, but it is worth it to continue to give students what they need and not necessarily what they deserve, even when they make very big mistakes because they just might have the capacity to make the changes they need for successful learning when given the chance."

What is remarkable in this excerpt from the reflective journal of an instructor is the transition of a pair of students from university probation for scholarly misconduct to published scientists contributing to the research community. The instructor speaks of the "long game" and believing in the value of supporting students. This transformation is situated in the nature of the CRE which directs students to produce scientific knowledge. There are several components of professional identity that play a role here. Being a scientist combined with the understanding that students need to be mentored, motivated and supported with the aim of allowing science to emerge allowed the forbearance in relation to earlier transgressions of the students. The students responded to the authenticity of the research by changing their behavior and really doing the science. It is unclear from the description exactly which practices supported this transformation, but what the instructor's professional identity facilitated is resilience and a clear understanding of what being a scientist involves.

## Discussion

The aim of this study was to explicate the professional identity of STEM faculty who instruct a CRE through an iREC and to consider the ways in which this identity contributes to the outcomes of these education reform efforts. The collective identity of instructors in the SEA program, as explicated in this study, consists of values related to scientific achievement and student success, which are facilitated by roles that include being a scientist, a mentor and an advocate, and a sense of self that allows for commitment and flexibility in working toward the success of every student. These features of the professional identity of STEM faculty in the context of their CRE classroom clearly explain the rich suite of facilitation that characterize CRE instruction and consequently the positive outcomes observed for students across diverse demographics (Hanauer et al., 2017, 2022a, 2023).

The interconnectedness of instructor identity, their pedagogy, and student outcomes is exemplified in the analysis of the reflective diary vignettes presented here. In each vignette, the instructor is faced with a challenge and a series of decisions that need to be made. The

positionality of the instructor, conceptualized through professional identity, is the intervening factor that directs the way the faculty member acts. In one case, the instructor makes all relevant accommodations to support a deaf student, in another the instructor works one-on-one on weekends and after class to help a student to discover a bacteriophage, and in another case the instructor “plays the long game” and transforms students who are failing and under university probation into publishing scientists contributing to science. It is the professional identity of the instructor in the context of their CRE classroom that drives the extended commitment and effort that these instructors evidently put into their work with students. The outcome of this increased effort is an educational experience that is rich for all students, and which also contributes quality data that advances science.

We infer that the professional identity of STEM faculty described in this study is fostered by particular features of a CRE and iREC. In a CRE, the centrality of authentic research positions faculty and students as researchers working together toward a shared goal of producing scientific outputs of value for the broader community. Consequently, in the role of the experienced scientist, instructors go beyond quality instruction and to also serve as a research mentor who works with each student toward their collective success. These aspects of professional identity are further reinforced through the iREC, which is designed to support each instructor in their role as a researcher and a research instructor and which affords them multiple opportunities to meet and collaborate with other members who share the goals and mission of the broader iREC community (Monti et al., 2024). Features of a CRE and iREC, which foster the professional identity of STEM faculty described in this study, therefore underpin the success of the SEA program and CRE instruction more broadly.

The analysis presented here, at least as it relates to CRE instructors with the SEA program, also offers a perspective into the tension between being a researcher and a teacher in STEM that was described by Brownell and Tanner (2012). As uncovered in this current study, teaching, *per se*, is not undervalued by STEM faculty in relation to research. Rather, STEM faculty value teaching when it resembles how learning and development occur for those in the profession; that is, when scientific content, concepts, and skills are taught and learned in the context of engaging in and advancing authentic research. This is true for STEM faculty in the context of graduate education and, as described here, can also be true in undergraduate science education (Feldon et al., 2015). We therefore postulate that STEM faculty have historically undervalued teaching in undergraduate science education, in part, because the undergraduate science curriculum does not reflect how learning and development occur for those in the profession and because it does not contribute toward advancing science. When there is synergy between teaching and research, as in graduate education or a CRE, faculty are evidently committed teachers. Indeed, as described in Monti et al. (2024), STEM faculty in the SEA program are motivated to iteratively advance their pedagogy to support their students to engage productively in their classrooms. We therefore hypothesize that the current undergraduate science curriculum, which does not center authentic research, shapes both teaching and the learning experience in ways that fundamentally underpin the low persistence of undergraduate students in STEM.

## Limitations

The central limitation of the current study is that all the instructors who participated in this study came from the same

program, thereby reflecting a form of selection bias. The SEA-PHAGES program has an extensive network of instructors and schools and, as an iREC that is supported by funding from the Howard Hughes Medical Institute, has extensive interaction between instructors. This networked aspect of this program may have a facilitative aspect to the construction of a particular type of professional identity. It is unclear from the present study if instructors of CREs beyond the SEA-PHAGES program have a similar construct. This will need to be addressed in future research. A second limitation of the current study relates to the way the data were collected and analyzed. The process of data collection and analysis involved multiple stages of large group discussion and explication. This process can in itself lead to a higher degree of convergence than might happen with other data elicitation methods. While this is conducive for explicating shared identities that are agreed upon, it does not lend itself to the divergences which may be present.

## Conclusion

As exemplified in this study of professional identity, the way STEM faculty see themselves in the context of their classroom shapes their instruction and the corresponding educational experience and outcomes for their students. What this study makes clear is thus the value, if not necessity, of committing to STEM faculty in ways that affirm the type of professional identity described in this study. STEM faculty who are supported to engage in pedagogy that reflects this professional identity will afford their students rich educational experiences and outcomes. The traditional lab and lecture formats do not support this identity; the SEA iREC and the SEA-PHAGES CRE do, and serve as frameworks and examples for the types of resources and classrooms that should be afforded to all STEM faculty, as described in Hanauer et al., 2017 and Monti et al., 2024, under review. In particular, STEM faculty should be supported to integrate the roles as a researcher and as an educator, and to operate in communities that share such an integrated identity, be that within their departments, programs, various scientific organizations, and institutions. As seen here, such an integrated professional identity is not only possible but is also a far more positive identity position for faculty to occupy.

## Data availability statement

The original contributions presented in the study are included in the article/[Supplementary material](#), further inquiries can be directed to the corresponding author/s.

## Ethics statement

The studies involving humans were approved by the Institutional Review Board for the Protection of Human Subjects Professor of Criminology, Indiana University of Pennsylvania. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.





## Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. This research was funded by a grant awarded to DavH by the Howard Hughes Medical Institute (GT#12052).

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of *Frontiers*, at the time of submission. This had no impact on the peer review process and the final decision.

## References

- Auchincloss, L. C., Laursen, S. L., Branchaw, J. L., Eagan, K., Graham, M., Hanauer, D. I., et al. (2014). Assessment of course-based undergraduate research experiences: a meeting report. *CBE—Life Sci. Educ.* 13, 29–40. doi: 10.1187/cbe.14-01-0004
- Beijaard, D., Meijer, P. C., and Verloop, N. (2004). Reconsidering research on teachers' professional identity. *Teach. Teach. Educ.* 20, 107–128. doi: 10.1016/j.tate.2003.07.001
- Bourdieu, P. (1993). *Bourdieu: Critical perspectives*. Chicago, IL: University of Chicago Press.
- Brewer, C. A., and Smith, D. (Eds.). (2011). *Vision and change in undergraduate biology education: A call to action*. American Association for the Advancement of Science.
- Brownell, S. E., and Tanner, K. D. (2012). Barriers to faculty pedagogical change: lack of training, time, incentives, and tensions with professional identity? *CBE Life Sci. Educ.* 11, 339–346. doi: 10.1187/cbe.12-09-0163
- Cameron, C., Lee, H. Y., Anderson, C. B., Trachtenberg, J., and Chang, S. (2020). The role of scientific communication in predicting science identity and research career intention. *PLoS One* 15:e0228197. doi: 10.1371/journal.pone.0228197
- Chang, H., Ngunjiri, F. W., and Hernandez, K.-A. C. (2013). *Collaborative autoethnography*. 1st Edn. (New York: Routledge). p. 200.
- Chen, J. L., and Mensah, F. (2022). Toward socially just science teaching through professional development: the science teacher identity development and agency of two elementary teachers of color. *Sci. Educ.* 106, 385–411. doi: 10.1002/sce.21699
- D'Arcy, C. E., Martinez, A., Khan, A. M., and Olimpo, J. T. (2019). Cognitive and non-cognitive outcomes associated with student engagement in a novel brain chemo architecture mapping course-based undergraduate research experience. *J. Undergrad. Neurosci. Educ.* 18, A15–A43. doi: 10.1101/7684651
- Elgin, S. C. R., Hauser, C., Holzen, T. M., Jones, C., Kleinschmit, A., and Leatherman, J. (2017). Genomics education partnership. The GEP: crowd-sourcing big data analysis with undergraduates. *Trends Genet.* 33, 81–85. doi: 10.1016/j.tig.2016.11.004
- Feldon, D. F., Maher, M. A., Hurst, M., and Timmerman, B. (2015). Faculty mentors', graduate students', and performance-based assessments of students' research skill development. *Am. Educ. Res. J.* 52, 334–370. doi: 10.3102/0002831214549449
- Feser, M. S., and Haak, I. (2023). Key features of teacher identity: a systematic meta-review study with special focus on teachers of science or science related subjects. *Stud. Sci. Educ.* 59, 287–320. doi: 10.1080/03057267.2022.2108644
- Gee, J. P. (2002). "Literacies, identities, and discourses" in *Developing advanced literacy in first and second languages: Meaning with power*. Eds. M. J. Schleppegrell and M. C. Colombi (Routledge), 159–175.
- Graham, M. J., Frederick, J., Byars-Winston, A., Hunter, A.-B., and Handelsman, J. (2013). Increasing persistence of college students in STEM. *Science*, 341, 1455–1456. doi: 10.1126/science.1240487
- Hanauer, D. I., Graham, M. J., Arnold, R. J., Ayuk, M. A., Balish, M. F., Beyer, A. R., et al. (2022b). Instructional models for course-based research experience (CRE) teaching. *CBE Life Sci. Educ.* 21, 1–14. doi: 10.1187/cbe.21-03-0057
- Hanauer, D. I., Graham, M. J., Betancur, L., Bobrownicki, A., Cresawn, S. G., Garlena, R. A., et al. (2017). An inclusive research education community (iREC): impact of the SEA-PHAGES program on research outcomes and student learning. *Proc. Natl. Acad. Sci. USA* 114, 13531–13536. doi: 10.1073/pnas.1718188115
- Hanauer, D. I., Graham, M. J., Jacobs-Sera, D., Garlena, R. A., Russell, D. A., Sivanathan, V., et al. (2022a). Broadening access to STEM through the community

## Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

## Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/feduc.2024.1442306/full#supplementary-material>

- college: investigating the role of course-based research experiences (CREs). *CBE—life sciences. Education* 21:ar38. doi: 10.1187/cbe.21-08-0203
- Hanauer, D. I., Zhang, T., Graham, M. J., Adams, S. D., Ahumada-Santos, Y. P., Alvey, R. M., et al. (2023). Models of classroom assessment for course-based research experiences. *Front. Educ.* 8:1279921. doi: 10.3389/feduc.2023.1279921
- Hancock, S., and Walsh, E. (2014). Beyond knowledge and skills: Rethinking the development of professional identity during the STEM doctorate. *Stud. High. Educ.* 41, 37–50. doi: 10.1080/03075079.2014.915301
- Hernandez, P. R., Woodcock, A., Estrada, M., and Schultz, P. W. (2018). Undergraduate research experiences broaden diversity in the scientific workforce. *Bioscience* 68, 204–211. doi: 10.1093/biosci/bix163
- Hodkinson, H., and Hodkinson, P. (2004). Rethinking the concept of community of practice in relation to schoolteachers' workplace learning. *Int. J. Train. Dev.* 8, 21–31. doi: 10.1111/j.1360-3736.2004.00193.x
- Hurley, A., Chevrette, M. G., Acharya, D. D., Lozano, G. L., Garavito, M., Heinritz, J., et al. (2021). Tiny earth: a big idea for STEM education and antibiotic discovery. *MBio* 12. doi: 10.1128/mBio.03432-20
- Ibarra, H., and Obodaru, O. (2016). Betwixt and between identities: liminal experience in contemporary careers. *Res. Organ. Behav.* 36, 47–64. doi: 10.1016/j.riob.2016.11.003
- Jordan, T. C., Burnett, S. H., Carson, S., Caruso, S. M., Clase, K., DeJong, R. J., et al. (2014). A broadly implementable research course in phage discovery and genomics for first-year undergraduate students. *MBio* 5, e01051–e01013. doi: 10.1128/mBio.01051-134
- Krippendorff, K. (1980). *Content analysis: An introduction to its methodology*. Beverly Hills, CA: Sage Publications.
- Kogan, M. (2000). Higher education communities and academic identity. *High. Educ. Q.* 54, 207–216. doi: 10.1111/1468-2273.00156
- Kuh, G. D., and Whitt, E. J. (1986). *The invisible tapestry: Culture in American colleges and universities (ASHE-ERIC Higher Education Report, No. 1)*. Washington: The George Washington University.
- Lave, J., and Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press.
- Lundell, D., and Collins, T. G. (2001). "Towards a theory of developmental education: the centrality of discourse" in *Theoretical perspectives in developmental education*. eds. D. Lundell and J. L. Higbee (Minneapolis: Centre for Research on Developmental Education and Urban Literacy, General College, University of Minnesota), 3–20.
- Mendoza, P. (2007). Academic capitalism and doctoral student socialization: a case study. *J. High. Educ.* 78, 71–96. doi: 10.1080/00221546.2007.11778964
- Monti, D. L., Gill, J. C., Adair, T. L., Adams, S. D., Ahumada-Santos, Y. P., Amaya, I., et al. (2024). An inclusive research education community (iREC) model to facilitate undergraduate science education reform. *Front. Educ.* 9:1442318. doi: 10.3389/feduc.2024.1442318
- Nadelson, L. S., McGuire, S. P., Davis, K. A., Farid, A., Hardy, K. K., Hsu, Y. C., et al. (2017). Am I a STEM professional? Documenting STEM student professional identity development. *Stud. High. Educ.* 42, 701–7202. doi: 10.1080/03075079.2015.10708191
- O'Leary, N., and Cantillon, P. (2020). Why shouldn't we do that on placement if we're doing it in the real world? Differences between undergraduate and graduate identities in speech and language therapy. *Adv. Health Sci. Educ.* 25, 781–797. doi: 10.1007/s10459-020-09955-0
- Pérez Gracia, E., Serrano Rodríguez, R., and Pontes Pedrajas, A. (2019). Analysis of science and technology pre-service teachers' beliefs on the construction of the teachers'

professional identity during the initial training process. *Eur. J. of Math. Sci. Technol. Educ.* 15:em1756. doi: 10.29333/ejmste/1030641

President's Council of Advisors on Science and Technology (PCAST). (2012). *Report to the president on propelling innovation in drug discovery, development, and evaluation*. Available at: <https://obamawhitehouse.archives.gov/administration/eop/ostp/pcast/docsreports>

Raste, S. A., and Murthy, S. (2024). Professional identity development in bioscience education: A systematic review of the literature. *Educ. Res. Rev.* 19, 13–25. doi: 10.5897/ERR2023.4384

Rhoades, G. (2007). "The study of the academic profession" in *Sociology of higher education. Contributions and their contexts*. ed. P. J. Gumpert (Baltimore: The Johns Hopkins University Press), 113–146.

Rodenbusch, S. E., Hernandez, P. R., Simmons, S. L., and Dolan, E. L. (2016). Early engagement in course-based research increases graduation rates and completion of science, engineering, and mathematics degrees. *CBE—Life Sci. Educ.* 15:ar20. doi: 10.1187/cbe.16-03-011

Rodrigues, F., and Mogarro, M. J. (2019). Student teachers' professional identity: a review of research contributions. *Educ. Res. Rev.* 28:100286. doi: 10.1016/j.edurev.2019.100286

Russell, S. H., Hancock, M. P., and McCullough, T. (2007). The pipeline: benefits of undergraduate research experiences. *Science* 316, 548–549. doi: 10.1126/science.1140384

Shaffer, C. D., Alvarez, C., Bailey, C., Barnard, D., Bhalla, S., Chandrasekaran, C., et al. (2010). The genomics education partnership: successful integration of research into laboratory classes at a diverse group of undergraduate institutions. *CBE Life Sci. Educ.* 9, 55–69. doi: 10.1187/09-11-0087

Shahabi, M., Mohammadi, N., Koohpayehzadeh, J., and Arabshahi, S. K. S. (2020). The attainment of physician's professional identity through meaningful practice: a qualitative study. *Med. J. Islam Repub. Iran* 34:16. doi: 10.47176/mjiri.34.16

Shwartz, G., and Dori, Y. J. (2020). Transition into teaching: Second career teachers' professional identity. *Eur. J. Math. Sci. Technol. Educ.* 16:8502. doi: 10.29333/ejmste/8502

Wald, H. S., White, J., Reis, S. P., Esquibel, A. Y., and Anthony, D. (2018). Grappling with complexity: medical students' reflective writings about challenging patient encounters as a window into professional identity formation. *Med. Teach.* 41, 152–160. doi: 10.1080/0142159X.2018.1475727

Wallenburg, I., Hopmans, C. J., Buljac-Samardzic, M., den Hoed, P. T., and IJzermans, J. N. (2016). Repairing reforms and transforming professional practices: a mixed-methods analysis of surgical training reform. *J. Profess. Organiz.* 3, 86–102. doi: 10.1093/jpo/jov012

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*: Cambridge University Press.

Copyright © 2024 Hanauer, Alvey, An, Bancroft, Butela, Coleman, Clase, Collins, Conant, Connerly, Connors, Dennis, Doyle, Edwards, Fillman, Findley, Frost, Gainey, Golebiewska, Guild, Gusk, Johnson, Johnson, Klyczek, Lee-Soety, Lindberg, Mastropaolo, Merkle, Mitchell, Molloy, Nieto, Nissen, Perez Morales, Peters, Pfeifer, Pollenz, Preuss, Rosas-Acosta, Saha, Sprengle, Sunnen, Tobiason, Tolsma, Ware, Ahumada-Santos, Alvarez, Anderson, Ayuk, Báez-Flores, Bailey, Baliraine, Behr, Beyer, Bhalla, Bono, Breakwell, Byrum, Duffy, Gleichsner, Harrison, Ho, Hughes, Kagey, Kohl, McClory, Moyer, Mussi, Nance, Nsa, Page, Parra Unda, Rocheleau, Swerdlow, Thoenke, Valentine, Vega, Ward, Williams, Wisner, Biederman, Cresawn, Graham, Hatfull, Heller, Jacobs-Sera, Monti, Ramakrishna, Russell and Sivanathan. This is an open-access article distributed under the terms of the [Creative Commons Attribution License \(CC BY\)](https://creativecommons.org/licenses/by/4.0/). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.