Paper ID #25407

Examining the Relationship of Active Team-based Learning and Technology and Engineering Students' Research Self-efficacy in a Cybersecurity Traineeship Class

Dr. Rylan C. Chong, Chaminade University

Dr. Rylan Chong is a data scientist in the Division of Natural Sciences and Mathematics at Chaminade University of Honolulu. He earned his bachelor's degree in Computer Science from Chaminade University of Honolulu. Dr. Chong has a master's degree from Purdue University in Information Security. He specialized in biometric systems and human factors during his master's degree. Dr. Chong completed his Doctor of Philosophy degree in Information Security and a Graduate Certificate in Information Security Policy at Purdue University. His dissertation work investigated the relationships of social cognitive career theory factors and cybersecurity research self-efficacy of former and current college students.

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Abstract

This research paper investigated the relationship of a cybersecurity active team-based learning research class and technology and engineering students' research self-efficacy. In addition, this study examined whether the relationship was different between genders. The students in the class were from eight universities and worked in teams with a mentor from a government agency or lab who provided them with a real unclassified cybersecurity problem. The study was conducted in 2016 and included a sample of 18 students (males=13 and females=5) who responded to a pre-survey and a post-survey (Cronbach's alphas for both surveys =.96) that measured researched self-efficacy using a 100-point Likert scale (0=complete uncertainty and 100=complete certainty). Due to a small sample, a Wilcoxon Signed Rank Test and a Mann-Whitney U Test were used to analyze the data. As part of the posttest, students were asked open-ended questions about their negative and positive experiences of the class that was analyzed using qualitative inductive and summative strategies. The study found the following, students' research self-efficacy posttest score was higher than pretest, and the observed difference was statistically significant. Both males and females had a higher research self-efficacy posttest score than pretest. The observed difference of the pretest and posttest for males was found to be statistically significant. Males had a higher research self-efficacy posttest score compared to females, but the observed difference was not statistically significant. The qualitative analysis results are, increasing self-efficacy could be attributed to students (1) having the feeling that they are gaining knowledge, skills, and abilities in research; (2) having a mentor to guide and learn from; (3) working on a real-world cybersecurity problem; (4) working in a team that is cohesive; and (5) do not feel they have a short amount of time to work on a project. It is important to note that the results should be interpreted carefully, because of the small sample and large variances.

Introduction

Cyber technologies are growing at a substantial rate and are impacting almost every sector of society. These cyber technologies provide innumerable benefits that mostly result in improving modern life. However, along with the benefits, cyber threats are increasing in occurrences, unpredictability, size, and speed [1]–[3], and that affects our national, social, and economic security [4]. Adding to this growing cyber threats is a shortage of cybersecurity researchers and workforce talent [5]–[7]. This talent shortfall is increasing as the scope of society's cybersecurity needs continue to expand. To close the gap, several authors [8]–[13] have recommended an effort to grow the number of people in cybersecurity who have competencies in research. This focus would result in a workforce able to identify and define problems, think critically to connect problems with solutions, develop projects and related plans, collect and analyze data, draw conclusions, communicate effectively, and work well in teams.

This study investigates the role of active team-based learning as a means of developing this needed cybersecurity workforce. Specifically, this study considers the relationship between student participation in a semester-long class focused on student teams working on current real-world cybersecurity research problems and their research self-efficacy. Research self-efficacy is described as a judgement of one's ability to perform research [14]. Research to date suggests there are relationships between self-efficacy, and students' academic success and career development factors. Therefore, this study seeks to better understand factors that may contribute to this increase.

Literature Review

This study considers the relationship among a series of interrelated concepts that have been the subject of significant research in education. These concepts are briefly summarized here, and relevant literature is discussed to provide context for the present study. Specifically, research self-efficacy, and self-efficacy more broadly are discussed with respect to their connection to various measures of students' academic success and career development. Following this, literature considering the relationships between various forms of active learning (including problem-based and project-based learning) and self-efficacy are examined.

Research self-efficacy

Self-efficacy can be minimally described as one's confidence. It was introduced by Bandura in 1977 who described it as a judgement of one's ability to execute a behavior or course of action [15]. Several authors found positive relationships between self-efficacy and career development factors. This implies, as self-efficacy increases, there is an increase in one's ability to link performed activities to career endeavors (i.e., outcome expectancy) [16]–[19]; an increase in career interests and related activities (i.e., interests) [16], [17], [20]; set higher career goals (i.e., performance goals) [18], [19]; higher likelihood to choose a particular career and related activities (i.e., choices) [20]; an increase in the intent to pursue a particular career and related activities (i.e., intentions) [16]; and an increase in academic performance [17]–[19].

Research self-efficacy is described as a judgement of one's ability to perform research [14]. While there are studies that focused on research self-efficacy, research self-efficacy is an area that is under-researched. The existing research found positive relationships between research self-efficacy and students' aspirations for research careers [21], [22], identifying with their professions [23], career interest [24], and academic performance [25].

Since one's self-efficacy connects to one's career development, the logical question is whether there are factors that can influence one's self-efficacy. Bandura introduced four factors correlated with self-efficacy, past performance (i.e., mastery of a task or behavior), vicarious experience (i.e., learning through others' experiences), verbal persuasion (i.e., positive and negative communication), and emotional and physical states (i.e., physical and emotional reactions) [15]. Further studies found self-efficacy to have a positive relationship to instructional design (i.e. practice-only class and practice and research methods class) [26], teaming [27], [28], and research training experience [21]–[23], [29].

Active learning

Active-learning was first introduced by Revans in 1983 while observing coal mine managers learning about the operation challenges by working with their personnel [30]. The definition of active-learning did not arise until 1991 when Bonwell and Eison described active-learning as "instructional activities involving students in doing things and thinking about what they are doing [31, p. 19]." Active learning, variously designed as project-based or problem-based, has been shown to have a positive relationship to self-efficacy [32]–[37], career interest [38]–[40], and academic performance [32], [33], [37], [41], [42]. In other words, students who experienced project-based or problem-based learning, were more likely to score themselves higher on self-efficacy, perform better academically, and pursue a career in their area of study.

Research self-efficacy and active learning summary

This section discussed self-efficacy's role in students' academic success and career development. Although research self-efficacy is an area that is under-researched, research self-efficacy was found to have a positive relationship to students' aspirations for research careers, identifying with their professions, career interests, and academic performance. There were several factors discussed that positively correlated to self-efficacy, which include past performance, vicarious experience, verbal persuasion, emotional and physical states, instructional design, teaming, and research training experience. This section included literature examining the relationships between active learning strategies and self-efficacy, career interest, and academic performance. The findings were that problem-based and project-based learning were positively correlated to self-efficacy, career interest, and academic performance.

Methods

The setting for this study was a class offered through the Information Security Research Education (INSuRE) project, which is a network of National Centers of Academic Excellence in Research (CAE-R) universities, the National Security Agency (NSA), various national labs (e.g., Oakridge National Lab and Sandia National Lab), and other government agencies and organizations [43]. The INSuRE project seeks to address cybersecurity challenges, specifically through developing research competencies and closing the workforce shortage gap. A core component of the INSuRE project is the offering of cybersecurity research traineeship experiences to graduate and undergraduate students from CAE-R universities. In these experiences, students performed a set of research tasks (see Table 1) in a team and worked directly with a mentor from a government agency or lab on a real unclassified cybersecurity problem [43], [44]. This study followed an INSuRE project class cohort in 2016, and considered the relationships between course participation, genders, and self-efficacy. The following hypotheses were examined:

H1: Participants will have a higher self-efficacy score in the posttest compared to the pretest.
H2: Males will have a higher self-efficacy score in the posttest compared to the pretest, and the observed difference will be statistically significant.
H3: Females will have a higher self-efficacy score in the posttest compared to the pretest, and the observed difference will be statistically significant.

H4: There will be no significant difference between genders posttest self-efficacy scores.

Table 1 INSuRE Class Activities and Deliverables

Activities	Description	Deliverables
Identify a problem and bid for a topic	• Explore literature on topics of interest to the students in the first two weeks of the semester. • Identify a problem within the topic. • Bid on the topics that can result in a semester-long team research project.	• Project bids
Literature review	• Teams perform a literature review on the assigned topic.	• Literature review
Research question and study design	• Identify, define, and refine research question based on the literature review. • Develop a study.	• Proposal
Collect data, analyze data, and draw conclusions	• Collect and analyze data. • Draw conclusions from the analyzed data.	• Weekly short write-ups on research progress with class instructor and mentor • Midterm progress report
Write a report	• Compile the work from the proposal, weekly check-ins, midterm progress report, and project.	• Final report
Oral presentation	• Orally present the research performed to other researchers who may or may not be experts on the topic.	• WebEx presentation
Collaborating with mentor	• Weekly in-person or conference call meetings with mentor.	• Weekly to bi-weekly meetings with mentor

Study design

This study was a descriptive study that used a single group, pretest and posttest design, and mixed methods concurrent embedded strategy. The single group was the INSuRE class. The class structure was predetermined prior to the research and the team members were assigned by the instructor of the class. This study utilized the pretest and posttest design [45] to address the investigation of the relationship of cybersecurity active team-based learning research experience and research self-efficacy; and examined whether the relationship was different between genders. The mixed methods approach was used to explain the pretest and posttest results based on three criteria introduced by Creswell and Clark: (1) to explain initial results by identifying factors that may have influenced the students' self-efficacy responses, (2) to improve the study by using the qualitative results to validate and improve the self-efficacy instrument, and (3) to describe the two cases (males and females) included in the study by identifying similar or different factors that could have influenced their self-efficacy responses [46]. The strategy used for the mixed methods approach was concurrent embedded strategy as it was performed during the post-survey stage of the study where participants responded to close-ended and open-ended self-efficacy questions. Concurrent embedded strategy is described as a one phase data collection where quantitative and qualitative data are both collected [47] to "further explore or explain the phenomenon under study" [48, p. 8].

Participants and approvals

A total of 18 students (males=13 and females=5) participated in the study. The class included primarily graduate students. All participants completed the INSuRE class and were part of a CAE-R university from Iowa, Indiana, Massachusetts, Pennsylvania, South Dakota, or Texas. Students worked in teams of two to four members that were assigned by the instructor of the class based on project bids discussed in Table 1. Student team membership varied as some teams included members that were all from the same school and education level (e.g., graduate and undergraduate), while others were comprised of students from different schools, or different education levels from different schools, or different education levels. This study was approved by the Institutional Review Board, and permission to recruit students was given by the professor instructing the class.

Researcher's bias

Analysis bias may have existed in this study, which is analyzing data conforming to a researcher's belief [49]. The researcher believed that there was a positive relationship between the cybersecurity active team-based research learning class and cybersecurity research self-efficacy. The bias may have influenced the way the researcher analyzed the qualitative data. For example, the researcher naturally overlooked factors.

Survey instrument and data collection

The study was performed in 2016. Before distributing the surveys to the participants, the pre-survey and post-survey self-efficacy questions were piloted among colleagues not affiliated with the INSuRE class and project who were familiar with the topic of self-efficacy and those who were not. The pre-survey and post-survey were designed with about 50 self-efficacy questions that were relevant to the INSuRE class and used a 100-point Likert scale (0=complete uncertainty and 100=complete certainty). The questions and Likert scale were derived primarily from the literature [50]–[54] that had Cronbach's alphas (i.e., survey instrument reliability score) that were around the acceptable range of scores .70 to .95 [55] as shown in Table 2; and Bandura's survey design [56]. However, it was observed many of the piloted participants did not complete the surveys, and provided feedback that the self-efficacy section was too long and the study will have an attrition challenge with participants. In the next iteration, the number of self-efficacy questions was reduced as shown in Table 3. The questions were selected based on the criteria that they aligned to traditional research competencies that students acquire through research programs [44], the research items covered as many items of the research self-efficacy subscales from the literature, and the items covered the primary research activities on the INSuRE class syllabus illustrated in Table 1.

An anonymous online pre-survey was distributed to students the week before the first research activity of the INSuRE class. Although there were a few students from different universities that started classes at different times based on their home university academic schedule, all the students started the first research activity at the same time. The survey collected demographic information and self-efficacy on particular research tasks. The INSuRE class completed a week prior to finals week based on students' home university academic schedule, and an anonymous online post-survey was distributed to students during finals week. The post-survey collected the self-efficacy on particular research tasks (i.e., same self-efficacy questions as the pre-survey) illustrated in Table 3 and open-ended questions that were derived and developed from Love, Bahner, Jones, and Nilsson's study [22] and Hutchison, Follman, and Antoine's second open-ended question [57] shown below in Tables 4. Both pre-survey and post-survey at the end of the study had a Cronbach's alpha of .96.

Table 2 Research Self-Efficacy Scales

Name of scale	# of subscales	# of items	Likert scale points	Average Cronbach's alpha	Cronbach's alpha range
Self-efficacy research measure (SERM) [54]	4	33	0=no confidence to 9=complete confidence	.90	.83-.94
Research self-efficacy scale (RSES) [51]	4	51	0=no confidence to 100=complete confidence	.89	.75-.96
Research self-efficacy (RSE) [52]	1	9	0=cannot do to 100=can do	One scale	.94
Clinical research appraisal inventory (CRAI) [53]	8	88	0=no confidence to 10=complete confidence	.95	.89-.97
Research self-efficacy [50]	3	28	0=no confidence to 100=complete confidence	.92	.90-.95

Note. Average Cronbach's alpha - is the average Cronbach's alpha of all subscales of a self-efficacy scale.

Table 3 Pre/Post Self-Efficacy Survey Questions [58, p. 128]

Research tasks	Confidence (0 to 100)
Identify a research problem	
Search an electronic database for literature	
Write a literature review	
Formulate a research a question	
Design a research study	
Collect data	
Analyze data	
Draw conclusions based on the analysis	
Report the data effectively (e.g., developing charts, figures, and tables)	
Write a research report	

Orally present your research to other researchers	
Collaborate with your mentor	

Note. 0=no confidence and 100=complete confidence.

Table 4 Post-Survey Open-Ended Questions

	Questions
Q1	What were the positive experiences during the INSuRE class that impacted your research self-efficacy ratings and explain?
Q2	What were the negative experiences during the INSuRE class that impacted your research self-efficacy ratings and explain

Data analyses

Quantitative

The data analysis used descriptive statistics of sample size (n), mean, median, and standard deviation (STD). Due to a small sample, two nonparametric analyses were used [59], [60]. Wilcoxon Signed Rank Test was used to analyze two dependent groups [59]. An example is analyzing the pretest and posttest data. The Mann-Whitney U Test was used to analyze two independent groups [59]. For instance, an analysis was performed to compare males and females.

Qualitative

The qualitative data were used to support the quantitative results. There were two qualitative analysis strategies used. The first strategy was inductive, which was used to derive emergent themes from words, phrases, and sentences from the data [61]. The inductive strategy was performed in three stages: (1) stage one was open coding, which is described as identifying and defining themes from the data; (2) stage two was axial coding, which is described identifying and defining the relationships of the themes; and (3) stage three was selective coding, which is described as a stage to refine the relationships defined in stage two [62]. The second strategy used was summative. In short, this strategy was used to quantify the themes [63] using the number of participants who responded to each theme. Participants' who responded to multiple themes would be categorized in more than one theme. For example, a participant with a response on *mentoring* and *team experience* would be placed and counted for both themes.

Results

Quantitative cybersecurity research self-efficacy

Using a Wilcoxon Signed Rank Test, this study found students' research self-efficacy posttest score was higher than pretest score, and the observed difference was statistically significant [43] in Table 5. Performing a Wilcoxon Signed Rank Test, males and females had a higher research self-efficacy posttest score than pretest. Males' observed pretest and posttest difference was found to be statistically significant in Table 6. Using a Mann-Whitney U Test, males had a higher research self-efficacy compared to females in the posttest, but the observed difference was not statistically significant as shown in Table 7. It is important to note that the male and female results should be interpreted carefully, because of the small sample and large variances.

Table 5 Students’ Research Self-Efficacy Pre-Survey and Post-Survey Results

	Pretest	Posttest
N	18	18
Mean	70.53	83.32
Median	75.46	86.12
STD	17.15	10.77
Wilcoxon Test	Z=-2.77	
P-Value	<.05**	

Note. **p<.05. **p<.01. ***p<.001. ****p<.0001*

Table 6 Males and Females Pre-Survey and Post Survey Results

	Males		Females	
	Pretest	Posttest	Pretest	Posttest
N	13	13	5	5
Mean	76.18	84.33	55.85	80.70
Mean difference	8.15		24.85	
Median	77.17	86.83	67.33	84.25
STD	10.52	7.81	23.36	17.25
Pre and Post Wilcoxon Test	Z=-2.41		Z=-1.75	
Pre and Post P-Value	<.05*		>.05	

Note. **p<.05. **p<.01. ***p<.001. ****p<.0001*

Table 7 Males vs. Females Post-Survey Results

	Posttest-Males	Posttest-Females
N	13	5
Mean	84.33	80.70
Median	86.83	84.25
STD	7.81	19.80
Mann-Whitney U Test	U=34	
P-Value	>.05	

Note. **p<.05. **p<.01. ***p<.001. ****p<.0001*

Qualitative cybersecurity research self-efficacy

Positive factors that impacted students’ self-efficacy

Inductive and summative strategies were performed to supplement the quantitative results by identifying factors that influenced the students’ cybersecurity research self-efficacy scores. A total of 18 participants provided responses. Table 8 illustrates four themes on the positive factors that influenced students’ research self-efficacy.

Table 8 Positive Factors that Impacted Students' Self-Efficacy

Themes	Frequency of participants
Research competency gained	14
Mentor	7
Real-world cybersecurity problem	4
Positive team experience	4

Research competency gained was the first theme, which had the highest frequency of 14 participants who had this theme within their response. Research competency gained can be described as a student who gained a research skill, knowledge, or ability from the INSuRE class. Examples of responses include (1) "I was able to practice writing and presenting our research, which is not something that I am able to practice in typical classes," (2) "Learning about new experimental protocols…", and (3) "The increase in paper-reading abilities."

Mentor was the second highest frequency of seven participants. A mentor is described as a "personal guidance provided, usually by seasoned veterans… [64, p. 683]." Examples of responses include (1) "TD always seemed willing to help…," (2) "Guided research and feedback from TD…," and (3) "…professor guidance."

Real-world cybersecurity problem had four participants who provided a response. Real-world cybersecurity problem can be minimally described as problems that students work on that are relevant, current, and real. A few responses include (1) "Working on interesting problems…," (2) "…interest in the research…," and (3) "…exposure to modern problems…."

Positive team experience had a frequency of four participants. Positive team experience is described as positive experiences while working in a team. Examples of responses include (1) "…actively working with others," (2) "Team cohesiveness…," and (3) "It was an overall good experience to meet new people."

<u>Negative factors that impacted students' self-efficacy</u>

Along with positive factors, this section identified negative factors that impacted students' research self-efficacy illustrated in Table 9. A total of 12 participants provided responses. It is worth noting that there were several participants who did not provide a response on negative experiences that influenced their cybersecurity research self-efficacy. Three participants responded with "NA or none" and the responses from three other participants did not relate to the question.

Table 9 Negative Factors that Impacted Students' Self-Efficacy

Themes	Frequency of participants
Negative team experience	6
Time to work on project	4
No research competency gained	3

Negative team experience had the highest frequency of six participants. Negative team experience are factors from the students' responses on bad experiences while working on their team. Examples of responses include (1) "…having a group member not do their work and dump it on other teammates," (2) "Micro-managing other group members," and (3) "…communication issue with teammates…."

Time to work on project was the second highest frequency of four participants. Time to work on project is described as the length of time to work on the project. A few responses include (1) "Time frame is too short," (2) "Three months is really a short time to perform literature survey, identify the problems, design a solution and implementing it with proper test cases," and (3) "The time was less."

No research competency gained had three participants who responded. No research competency gained can be described as students not gaining a skill, knowledge, or ability, because of negating factors. Examples of responses include (1) "Not enough emphasis on reading background materials or reading survey papers of the material…That way students can be more familiar with the background material for each of the projects," (2) "In order to get server setup…lots of configuration issues came up with were time consuming…," and (3) "the main negative experience was difficulties during the setup of research equipment."

Positive and negative factors for males and females

Tables 10-13 illustrate the breakdown of males' and females' positive and negative response factors that impacted cybersecurity research self-efficacy in regard to Tables 8 and 9. There were 13 males and five females who provided positive responses. There were nine males and three females who provided negative responses. The highest positive factor for both males and females was research competency gained, with a frequency of nine males and five females. Students felt higher confidence when they learned a cybersecurity research skill, knowledge, or ability. The highest negative factor for both males and females was negative team experience, with a frequency of four and two respectively. Students' confidence decreased when they had problems working with their team members.

Table 10 Positive Factors that Impacted Self-Efficacy of Males

Themes	Frequency of participants
Research competency gained	9
Mentor	5
Real-world cybersecurity problem	3
Positive team experience	3

Table 11 Negative Factors that Impacted Self-Efficacy of Males

Themes	Frequency of participants
Negative team experience	4
Time to work on project	3
No research competency gained	3

Table 12 Positive Factors that Impacted Self-Efficacy of Females

Themes	Frequency of participants
Research competency gained	5
Mentor	2
Real-world cybersecurity problem	1
Positive team experience	1

Table 13 Negative Factors that Impacted Self-Efficacy of Females

Themes	Frequency of participants
Negative team experience	2
Time to work on project	1

Discussion

This study investigated the relationship of a cybersecurity active team-based learning research class and technology and engineering students' research self-efficacy. In addition, this study examined whether the relationship was different between genders. Addressing Hypothesis 1 (H1), this study found that the students' self-efficacy posttest was higher than pretest, and the observed difference was statistically significant. Both males' and females' self-efficacy posttests were higher than pretests. The observed difference for the males was found to be statistically significant (i.e., addressing H2 and H3). Comparing the self-efficacy posttest scores between genders, males had a higher self-efficacy than females, but the observed difference was not statistically significant (i.e., addressing H4). The results indicate that there was a relationship between participation in the INSuRE class and students' cybersecurity research self-efficacy, and a relationship exists for males taking the class and their research self-efficacy. Factors described by both males and females that may increase one's cybersecurity research self-efficacy include (1) enabling the students to feel that he or she is gaining knowledge, skills, and abilities in research; (2) having a mentor available; providing students real-world problems; and (3) ensuring the team is working cohesively. There are factors that an authority figure needs to address as these factors can negatively influence self-efficacy, including (1) negative team experiences, (2) a short time frame to work on a project, and (3) the feeling that the students are not improving their competency.

Noted earlier, the results should be interpreted carefully. This study used a small sample size and had large variances. A reason for the large variances, is due to the small sample size. One of the reasons for the small sample size is that there is a gender gap disparity in the cybersecurity area [8], [65] and some students may have been unwilling to take this study. If it was the case that students may have been unwilling to participate in this study, the reasons of the unwilling students could range from low cybersecurity research self-efficacy, poor performance in the class, or that they could not participate in the posttest as it was distributed during finals week. If the unwilling students who had low research self-efficacy or poor performance were included, it was highly likely that the posttest scores would have been lowered and no observed differences would be found. In addition, the open-ended questions likely would include a higher amount of negative responses. For the students who could not participate, because of finals or end of the school year activities, the posttest scores could have been higher or lower, and the open-ended questions would likely have an adequate distribution of positive and negative responses.

Conclusion and future research

This study investigated the relationship of a cybersecurity active team-based learning research class and technology and engineering students' research self-efficacy. This study also examined if the relationship was different between genders. The study used a sample of 18 college students (i.e., primarily graduate students) who were from eight universities that worked in a team with a mentor from a government agency or lab who provided a real unclassified cybersecurity problem. The study was a descriptive study that used a single group, a mix method concurrent embedded strategy, pretest and posttest Likert scale surveys, and the posttest included open-ended questions used to collect qualitative data. Nonparametric analyses were performed, because of the small sample. Inductive and summative strategies were used to analyze the qualitative data. This study found that there was a relationship between students participating in the INSuRE class and students' cybersecurity research self-efficacy, and a relationship existed for males taking the class and their research self-efficacy. Females had a higher posttest research self-efficacy than pretest, but the observed difference was not statistically significant. The higher self-efficacy scores could be attributed to students (1) having the feeling that he or she is gaining knowledge, skills, and abilities in research; (2) having a mentor to guide and learn from; (3) working on a real-world cybersecurity problem; (4) working in a team that is cohesive; and (5) do not feel they have a short amount of time to work on a project. This study noted that the results should be interpreted carefully as this study used a small sample and had large variances. The next step for this study will be to retest the research self-efficacy pre-survey and post-survey, because of the small sample used for this current study. Another future research will be to further investigate the relationships of teaming, mentoring, and working on a real-world problem and self-efficacy as they were introduced in the qualitative results.

Acknowledgements

The author thanks Dr. Helen Turner, Dr. Jonathan Baker, Dr. Chrystie Naeole, Lynn Haff, the INSuRE project, and the Division of Natural Sciences and Mathematics at Chaminade University of Honolulu for their insights to the development of this article.

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