Visualization: A Conduit for Collaborative Undergraduate Research Experiences

Dr. Vetria L. Byrd Ph.D., Purdue University

Dr. Vetria Byrd is an assistant professor in the Department of Computer Graphics Technology in the Polytechnic Institute at Purdue University in West Lafayette, Indiana. Dr. Byrd is the founder and organizer of the biennial Broadening Participation in Visualization (BPViz) Workshop co-funded by The Committee on the Status of Women in Computing Research/Coalition to Diversify Computing (CRA-W/CDC) and the National Science Foundation (NSF). Dr. Byrd has given numerous invited talks and workshops on visualization including: XSEDE14 plenary address (featured in HPC Wire online magazine), and an invited presentation at The Banbury Center at Cold Spring Harbor Laboratory. Dr. Byrd works with XSEDE to provide on campus training on scientific visualization. She was the Principal Investigator for the highly competitive NSF VisREU Site: Research Experience for Undergraduates in Collaborative Data Visualization Applications for 2014/2015 at Clemson University. Dr. Byrd continues to mentor VisREU research fellows as well as students at Purdue University. Dr. Byrd received her graduate and undergraduate degrees at the University of Alabama at Birmingham, in Birmingham, Alabama which include: Ph.D. in Computer and Information Sciences, Master's degrees in Computer Science and Biomedical Engineering and a Bachelor's degree in Computer Science. Dr. Byrd's research interests include: data visualization, high performance visualization, big data, uncertainty visualization, collaborative visualization, broadening participation and inclusion.

Dr. Camilo Vieira, Purdue University, West Lafayette (College of Engineering)

PhD Computational Science Education - Purdue University Master of Engineering in Educational Technologies - Eafit University Systems Engineer - Eafit University

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Abstract

Evidence of the importance of visualization can be seen in the role visualization continues to play in informed decision making [1-4], data analysis [5], explanations of complex data sets [6-8], detection of trends and patterns [9], and storytelling [10-12]. The need to diversify a field with such far-reaching influence is imperative [13]. Visualization is the process of transforming raw, complex data into a visual representation that provides insight. In order to prepare the next generation of researchers and scientists to make transformative and innovative discoveries in a data-driven world, exposure to the process, tools and techniques of data visualization must begin early. Many students and some faculty are not aware of the data visualization process, the value of visualization, the purpose of visualization or the benefits of visualization in academia, research, and industry. The 2014/2015 NSF REU Site (Award 1359223) summer research experience for undergraduates in collaborative data visualization applications was designed to address this need. Goals of the program are to: (1) introduce data visualization at the undergraduate level, (2) strengthen student skills and capabilities in data visualization, (3) broaden participation in visualization among women, members of underrepresented groups and students from institutions with limited research infrastructure, and (4) encourage students to pursue graduate degrees in STEM. Visualization training is part of the core summer curriculum. Undergraduates, STEM and non-STEM majors, participate in the program. Results: The 2014/2015 program cumulatively recruited a total of 22 participants: 11 (50%) female, 11 (50%) male; 4 (18%) of participants were from historically black colleges or universities (HBCU), 1 (5%) from Hispanic serving institutions (HSI), 5 (23%) first-generation college students. Students were also recruited from institutions with limited research opportunities: 10 (45%) of the 2014/2015 cohort were from non-PhD granting institutions. The program provided diversity in content, projects and participant ethnicities: 6 (27%) African American, 1 (5%) Asian, 4 (18%) Hispanic/Latino, 1 (5%) Native American/American Indian, and 10 (45%). In 2014 the program received 26 applications. In 2015 the program received 205 applications for 10 slots. The program included multidisciplinary research projects in computer science, engineering, genetics and biochemistry, sociology, molecular modeling and simulation, inorganic chemistry, and athletics. Students participating in the summer program reported majoring in engineering, computational biology, computer science, engineering, mathematics, and information systems. The combined 2014/2015 cohorts reported: 21 accepted student conference poster presentations, 15 accepted student conference talks, and 55 student REU site presentations (including midterm, final presentations and presentations to incoming freshmen from underrepresented groups) about the summer program and their research. Conclusion: The demand for persons with data visualization skills will continue to grow as data continues to grow in volume, size and variety [14]. The increase in applicants for the summer program suggests there is growing interest in data visualization at the undergraduate level, across disciplines and among STEM and non-

STEM majors. This paper provides an overview of the program, recruitment effort, outcomes and assessment.

Introduction

The need for knowledgeable persons with an understanding of the visualization process continues to grow as data sets continue to grow in size (volume), type (variety), and speed of data processing (velocity) [14]. To meet this need exposure to tools and techniques of visualization should begin early; consequently, the idea for a summer research experience for undergraduates in visualization was born. The goal of the research site is consistent with the goal of the NSF-REU program: to provide promising undergraduate students with a complete, mentored research experience, to better prepare these students for graduate school or professional pursuits and encourage them to pursue a career in science [15]. The impact of undergraduate research experiences have been well documented [16], [17], [18], [19]. Faculty members generally agree that there are significant educational benefits to the undergraduate research experience [20], [21]. Students are thought to develop expertise in a specific area of specialization, gain a better understanding and appreciation of the research process, acquire communication, problem-solving, and critical thinking skills [22], develop the ability to think independently [23] as well as increase originality, creativity, and curiosity [24]. Particularly, visualization encompasses science, technology, engineering and mathematics and can be utilized as a pathway to STEM.

The goals of the NSF REU Site: Undergraduate Research Experience for Undergraduates in Collaborative Data Visualization Applications (VisREU) are three-fold:

(1) Introduce data visualization to undergraduates from all academic disciplines
(2) Provide foundational knowledge about the visualization process to undergraduate and faculty researchers
(3) Broaden participation in visualization across all disciplines

As a strategy to achieve these goals, the objectives for the REU Site are as follows:

(1) Engage undergraduates from all academic disciplines in the visualization process
(2) Identify a wide range of research projects with data visualization needs
(3) Recruit students, particularly women and members of underrepresented groups to participate in the summer research experience.

This paper provides cumulative findings from the first two years of the VisREU Site. This paper provides an overview of the summer program, cumulative demographics, insight into The VisREU Experience, which includes the approach and survey research instrument used to gather feedback from student participants, and pre- and post-survey results.

REU Site Program

A review of NSF funded REU sites in 2014/2015 revealed the VisREU Site was the only REU Site whose primary focus was data visualization. The program is pioneering in using data visualization as a tool to cultivate 21st Century skills. Twenty-first century skills include using a variety of techniques to be able to solve complex problems, to think critically about tasks, and to effectively communicate with people from a variety of different cultures [25]. The learning and use of data visualization tools and applications as a core part of this undergraduate program enable students to refine these skills during the VisREU Experience. The program established a mentored 8-week summer research and training program for 10 to 12 undergraduate students per year in the area of high performance visualization. The intended impacts of the program are to broaden participation in visualization at the undergraduate level while accelerating discovery and progress. The REU program was designed to give promising students a research experience that: (1) include relevant and intellectually challenging research projects, (2) provide a sense of community among students, (3) engage their social skills, and (4) contribute to the overall success of the program.

The Research Team

Each student researcher participated in research activities as a member of a REU Team, their Research Lab, and their REU cohort. In keeping with the traditional REU student model, each research team consisted of a REU Student researcher, a faculty mentor and members of the research faculty's lab (where applicable). A key enhancement to this model allowed for a unique feature of the VisREU Site to include a visualization mentor in each student research team. The Visualization mentor worked closely with the VisREU student to ensure their understanding of the data visualization process, worked with the faculty research mentor to determine the data visualization needs of the project, and together with the VisREU student and faculty research mentor to help determine the best way to represent the research data and effectively communicate their results in a visual form. Figure 1 shows the traditional REU model (A) and the VisREU Site model (B) for student research teams. This arrangement fostered collaboration among team members, an appreciation of the visualization process and an understanding of the role visualization plays in discovery and analysis for both the undergraduate researcher and for the research team.

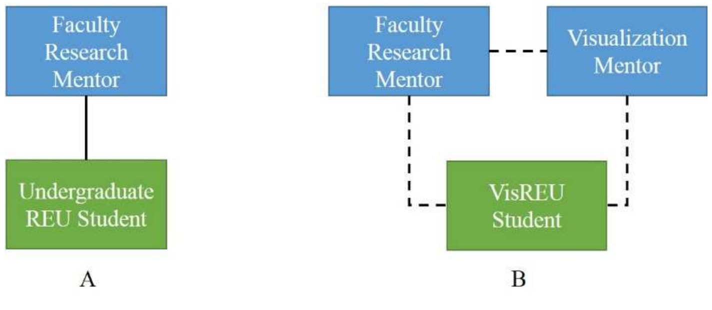

Figure 1. Traditional REU student research team model (A) versus VisREU student research team model (B). Dashed lines in (B) indicate the REU mentoring and collaboration structure within the VisREU Site.

Complementary outcomes of the VisREU Site are to (1) explore visualization as a conduit for collaboration, and (2) educate faculty researchers regarding the benefits of integrating data visualization into the systematic process of research sooner rather than upon completion of the process.

Research Projects

Research projects in the VisREU Site were strategically varied across many academic domains; however the common thread that connected them is visualization. Visualization lends itself to interdisciplinary and collaborative work. To foster a community of collaboration, interdisciplinary research projects are ideal. The first year (2014) of the VisREU Site, the program hosted projects with data visualization needs from the following research areas: Anthropology, Genetics and Biochemistry, Geophysics, Sociology, Molecular Modeling and Simulation, Plant Population and Community Biology, Inorganic Chemistry, Parks Recreation Tourism Management, Social Media, Social Media Listening, Social Networks, Management of Information Systems, Computer Science, Physical Chemistry, Digital Humanities, Anthropology and Sociology, Biological Sciences, Education and Electrical and Computer Engineering. In the second year (2015) the breadth of research projects continued to expand to include projects from faculty researchers in Civil Engineering, Athletics, Watershed Restoration and Protection Plan Development, Forestry and Natural Resources, Industrial Engineering, and Biological Sciences. The program also hosted digital humanities research projects for two consecutive years.

During the 8-week program students are introduced to the visualization process, and participate in workshops designed to give an overview of different types of data visualization tools, methods and techniques. They learn the seven steps of visualization [26] and gain hands-on experience navigating through the visualization process as they work to visualize project data and gain more insight into how to effectively represent data.

Recruitment and Student Participants

All undergraduate students with an interest in visualization, enrolled in a U.S. university and in good academic standing, were encouraged to apply to the REU program. The recruiting strategy included emailing targeted discipline-specific mailing lists. Examples include: African American PhD's in Computer Science (AAPHDCS), Hispanic serving mailing lists, and Broadening Participation in Visualization (BPViz) mailing list, infovis.og). Additionally, other communications included emailing colleagues about the program, emailing career services departments at historically black colleges and universities (HBCU's) and, minority serving institutions (MSI's), and marketing by the principal investigator/coordinator, at conferences (XSEDE, IEEE Vis, and Super Computing). The REU Site received 26 applications in 2014, its inaugural year. Having advertised the program via email, social media, word of mouth, and websites like pathwaystoscience.org, the program received wide spread coverage the next year which resulted in 205 applicants in 2015. The increase in applicants was interpreted by the PI and REU Site team as an indicator of need and interest in visualization at the undergraduate level. Unfortunately the program was limited by the number of students it could fund per summer. To date the program has supported a total of 22 students over the two year period. Acceptance rate for the program went from 38% in 2014, down to only 6 % in 2015. Table 1 summarizes the number of applicants, participants and acceptance rates for 2014 and 2015.

Table 1. VisREU Site Acceptance Rates for 2014/2015

	Applicants vs Participants		
	Applicants	Participants	Acceptance Rate
2014	26	10	38%
2015	205	12	6%

Cumulative Demographics

The program introduced visualization and research to undergraduate students from universities across the United States. To date, 18% percent of participants were from historically black colleges or universities, and 5% from Hispanic serving institutions. The gender distribution among participants was evenly split: 50% (male), 50% (female) across 2014/2015. Female students (n = 11) participating in the summer program reported majoring in engineering (27%), computational biology (9%), computer science/engineering (36%), mathematics (18%), information systems (9%). Male students (n = 11) reported majoring in psychology/Spanish (9%), mathematics (36%), computer information systems (27%) and engineering (27%).

Table 2 shows the demographics of VisREU participants for 2014 and 2015. The first year of the program (2014) 10% of participants reported having participated in a past REU-like experience. In 2015, 42% of students reported participating in some kind of research program or having been exposed to the research environment. Cumulatively, the gender distribution was evenly split. Table 2 shows 30% of the cohort was female in 2014 and 67% of the cohort was female in 2015. In the two years of its offering, the program saw an increase in ethnic diversity in its cohorts. In 2014, 30% of the cohort was African American but had no representation from Hispanic/Latino and Native American/American Indian communities. In 2015, the program showed more diverse participation: 25% African American, 33% Hispanic/Latino and 8% Native American/American Indian. Academically, the 2014 cohort was 10% freshmen, 30% sophomores, 50% juniors and 10% seniors. The 2015 cohort was made up of 8% freshmen, 25% sophomores, 45% juniors and 25% seniors.

Cumulatively, to-date, the program has hosted a diversity of participants: African American (27%), White (45%), Hispanic/Latino (18%), Native American (5%), and Asian (5%). The Site has mentored 22 undergraduates: freshmen (9%), sophomores (27%), juniors (45%) and seniors (18%).

Table 2. Demographic Information of 2014/2015 VisREU Participants

Year	**Number of Participants**	**% Past REU Experience**	**% Female**	**% Ethnic Diversity AA/HS/NA**	**% Fr/So/Jr/Se**
2014	10	10%	30%	30/0/0	10/30/50/10
2015	12	42%	67%	25/33/8	8/25/42/25

AA: African American, HS: Hispanic/Latino, NA: Native American/American Indian

Project descriptions, and desired skills, provided by the researcher and visualization mentor, were posted on the program website. During the application process student were asked to select and rank, in order of preference, three projects that interest them, and that they felt their skill sets would enable them to successfully complete project milestones. Students were also asked to list their skills and provide a self-assessment in regards to their level of experience visualizing data. Using this information as a guide, students were matched with research projects based on their skill, interest and the needs of the project. Gender and ethnicity pairing between students and research mentors were not a factor when projects were assigned. A review of student/mentor pairing for the 2015 VisREU cohort results are shown in Table 3 and Table 4. Although unplanned, 41% of the student/mentor pairing resulted in same gender pairings for male students. The data showed 23% of the student/mentor pairing for same gender paring for female students. Nine (9) percent of the male students were paired with female mentors and 27% of female students were paired with male mentors. Table 4 shows student/mentor parings by ethnicity.

Table 3. Student/Mentor Gender Pairing

	Student / Mentor		
	REU Student Gender	**Primary Research Mentor Gender**	**Percent**
Gender Match	Male	Male	41%
	Female	Female	23%
	Male	Female	9%
	Female	Male	27%

Table 4. Student Mentor Ethnicity Match

Ethnicity	**Student / Mentor**		
	REU Student Ethnicity	**Research Mentor Ethnicity**	**Percent**
Ethnicity Match	African American	White	27%
	White	White	45%
	White	Asian	5%
	Hispanic/Latino	White	5%
	Hispanic/Latino	Asian	9%
	Native American/ American Indian	Asian	5%
	Asian	Asian	5%

The VisREU Experience

The goal of the VisREU Site is to establish a mentored, 8-week summer research and training program for undergraduate students in the area of data visualization. Student contributions focus on visualization components of research projects. The program spans multiple domains to create a multidisciplinary research experience for undergraduates. The intended impact is to broaden participation in visualization while accelerating discovery and progress. We address the need to explore visualization jointly with respect to research projects by: (1) involving 10 to 12 students per summer directly in data driven visualization with mentored research projects conducted in collaboration with other subfields, (2) providing training in tools and technologies that are common in visualization research, (3) inspiring participating students to consider research as a career path and pursue visualization at the graduate level and (4) specifically targeting participation of women and underrepresented groups from institutions with limited cyberinfrastructure resources. The approach section consists of two parts. The first part describes VisREU Experience. The second part describes the survey research instrument for collecting student feedback.

Approach

The VisREU Site provides students with an authentic research experience that engages and fosters creativity and exploration. Research faculty provided project descriptions and desired skills of the students but there were no prerequisites for the visualization aspect of participation. The VisREU research team assumed students participating in the program had no prior knowledge of the visualization process and little to no experience with visualizing data beyond using Microsoft Excel charts. To facilitate visualization literacy and capacity building in a collaborative manner, each year's cohort met regularly for visualization training as a group (during the 8-week program). Seminal visualization research papers were assigned as reading assignments and discussed as a group as part of the research methods module of the program. The first year of the program included one group session on research methods taught by research faculty. The second year the teaching of research methods was broadened to span several weeks of the program to help students take a first step towards developing and thinking critically about their research questions. This process provides a high level overview, sets the stage for more discipline specific research related details covered by faculty research mentors and fosters a more engaging dialog between students and faculty.

The cohort worked closely with their faculty research mentors on a wide and varied array of different visualization projects. To encourage interdisciplinary collaborations among students and faculty mentors, lab space equipped with research infrastructure needed to complete visualization tasks was available 24 hours a day, 7 days a week for the duration of the summer program. Access to the visualization facility fosters collaborations across research projects and disciplines. Students and their mentors have access to hardware and software, high-speed internet connection to the backbone of the campus network and access to the campus cluster as needed.

In the process of learning about the data visualization process, the VisREU cohorts learn of numerous visualization tools for different types of data. They learn to utilize visualization as a tool for analysis of data, to detect patterns, to think about and ask deeper questions, to show spatial relationships, and to tell their research story. Understanding the visualization process enables students to think critically about their results, and explore alternate solutions to complex problems.

Coupled with the REU Site's primary focus of research is the underlying goal of preparing students for the next chapter in their academic careers: graduate school. The program mentors students toward this goal by providing professional development opportunities, research lectures from faculty mentors (who highlight contributions from student researchers in their presentations), and various seminars on how to prepare for graduate school (informing students on what to expect in graduate school, technical writing, how to succinctly tell their story in an elevator pitch, and round table discussions with experts in the field). The VisREU program provides several mechanisms for presentation of results in the form of a midterm presentation of work in progress, a final paper submission and presentation open to the public. The 2014 and 2015 cohorts were given additional opportunities to perfect their presentation skills for multiple audiences from various backgrounds. The 2014 cohort participated in the student poster session at Extreme Science Engineering Discovery Environment (XSEDE) Conference in Atlanta, Georgia. The 2015 cohort participated in the student program at XSEDE15 Conference, in St. Louis, Missouri, in the 2015 NC/SC REU Site Mini-Symposium in Charleston, South Carolina, and presented their research projects to incoming freshmen to encourage them to consider adding a research experience to their academic plans. These opportunities took place as part of the VisREU Experience, rather than after completion of the program—another unique feature of the 2014/2015 VisREU Experience.

Survey Research Instrument

The A La Carte Student Survey Toolkit [27] is used to collect and report evaluation data from the VisREU Site. Survey instrument scales correspond to recommended indicators found to be common among CISE REU programs. REU PIs are able to select the scales and items as deemed appropriate for their site. A complete list of the scales available for measurement, as well as additional information about the survey research instrument is available on the CISE REU Toolkit web site http://reu.uncc.edu/toolkit/project-goals, hosted by University of North Carolina Charlotte (UNC). Upon completion of the program, students received a full survey instrument designed to capture feedback on the entire REU experience. For the purpose and scope of this paper, only questions that refer to the student's ability and willingness to participate in a collaborative environment are presented. Questions highlighted here were extracted from three sections of the survey research instrument: self-efficacy, research skills, and scientific leadership. The sections below describe survey questions from each of these survey sections. A total of 17 questions are provided: 5 from General Self-Efficacy, one (1) from Research Skills and Knowledge, and 11 from Scientific Leadership.

General Self-Efficacy

Feedback from students on general self-efficacy addresses student confidence in their ability to perform each of the activities listed in Table 5. Students select the rating that best describe their degree of confidence by using the following scale: Strongly Agree (5), Somewhat Agree (4), Neutral (3), Somewhat Disagree (2), and Strongly Disagree (1).

Table 5. General Self-Efficacy Student Survey 2015 Post Questions

	Rate your degree of confidence with the following statement. I can:
Q1	Work with others to investigate a research problem
Q2	Discuss research with other students
Q3	Discuss research with graduate students
Q4	Discuss research with professors
Q5	Discuss research at a professional meeting or conferences

Research Skills and Knowledge

Only one question from Research Skills and Knowledge fell within the scope of this paper and is listed in Table 6. The question asks students to consider the primary discipline of their REU project when responding. Students indicate how much they know about the topic (shown in Table 6) about research skills and knowledge using a scale from 1 to 5, with 1 being "nothing at all" and 5 being "a great deal."

Table 6. Research Skills and Knowledge

Q6	Working collaboratively with others

Scientific Leadership

The Scientific Leadership section addresses student views about leadership and teamwork; all questions from the Scientific Leaders section of the survey research instrument are provided in Table 7. These questions focus on feedback regarding getting people to work together effectively to answer a question or solve a problem. Teamwork includes communication, collaboration, etc. Students choose the one number that indicate their agreement with the statement shown in Table 7 where 5 = Strongly Agree, 4 = Somewhat Agree, 3 = Neutral, 2 = Somewhat Disagree, and 1 = Strongly Disagree.

Table 7. Scientific Leadership

Q7	I know how to cooperate effectively as a member of a team
Q8	I find it easy to follow instructions or take orders from others
Q9	I have high confidence in my ability to function as part of a team
Q10	I can provide strong support for other members of any team that I am on
Q11	I know how to be a good team member
Q12	I know a lot about what it takes to be a good leader
Q13	I know what it takes to help a team accomplish its task
Q14	I am confident of my ability to influence a team I lead
Q15	I know how to encourage good team performance
Q16	I am able to allow other team members to contribute to the task when leading a team
Q17	I can train or supervise students and/or technicians in the laboratory

Results

Students are encouraged to participate and complete pre- and post-surveys; however, participation in the survey is voluntary. Surveys are administered electronically and via email by UNC Charlotte under the direction of Dr. Audrey S. Rorrer. The pre-survey is provided during the first week of the program. The post-survey is provided during the last week of the program. Survey responses are collected and de-identified before being made available to the PI. The first year of the VisREU Site resulted in lackluster student participation—less than 4 students completed surveys. Greater effort was made in 2015 to stress the importance of feedback. As a result, 92% (11 out of 12) students completed pre-surveys, 67% (8 out of 12) completed post-surveys. The following sections present survey responses from 2015 VisREU Cohort.

2015 Pre-Survey Results

Pre- and post-surveys consisted of identical questions and categories of questions each year. This section details results from questions from General Self-Efficacy, Research Skills and Knowledge, and Scientific Leadership that provide feedback on the student's ability and willingness to work in collaborative environments. Eleven (n=11) out of 12 students from the 2015 VisREU cohort completed the pre-survey.

General Self-Efficacy Pre-Survey Results

Table 8 shows the 2015 VisREU General Self-Efficacy Pre-Survey results. Participants responded: Strongly Agree (SA), Somewhat Agree (SWA), Neutral (N), Somewhat Disagree (SWD) or Strongly Disagree (SD) to the statements Q1 to Q5. Students reported a higher self-efficacy related to work with others to investigate a research problem (Q1) and to discuss research with other students (Q2), than to the other three statements. The statement Q5 (i.e. discuss research at a professional meeting or conference) showed a portion of the group with a neutral opinion (18%) about it, or 9% of the participants somewhat disagreed they could discuss research at a professional meeting or conference.

Table 8 General Self-Efficacy 2015 Pre-Survey Results (n = 11)

	I can:	SA	SWA	N	SWD	SD
Q1	Work with others to investigate a research problem	45%	55%			
Q2	Discuss research with other students	55%	45%			
Q3	Discuss research with graduate students	36%	45%	18%		
Q4	Discuss research with professors	36%	55 %	9%		
Q5	Discuss research at a professional meeting or conference	45%	27%	18%	9%	

Strongly Agree (SA), Somewhat Agree (SWA), Neutral (N), Somewhat Disagree (SWD) or Strongly Disagree (SD)

Research Skills and Knowledge Pre-Survey Results

Participants were asked to indicate how much they know about working collaboratively with others using a 5 point scale with 5 being "a great deal," 4 being "somewhat a great deal," 3 being "neutral" 2 being " knowing something but not a lot," and 1 being "nothing at all." Fifty five percent indicated knowing a great deal about working collaboratively with others; 45% indicated knowing somewhat a great deal about working collaboratively with others.

Scientific Leadership Pre-Survey Results

Table 9 shows Scientific Leadership pre-survey results. Participants were asked to indicate: Strongly Agree (SA), Somewhat Agree (SWA), Neutral (N), Somewhat Disagree (SWD) or Strongly Disagree (SD) to the statements in Table 10. Ninety-one (91%) strongly agreed they know how to cooperate effectively as a member of a team, and 9% somewhat agreed. Fifty-five (55%) strongly agreed it is easy to follow instructions effectively as a member of a team, 36% somewhat agreed, and 9% were neutral. Seventy-three percent (73%) strongly agreed they have high confidence in their ability to function as part of a team, and 27% somewhat agreed. Ninety-one percent (91%) strongly agreed they can provide strong support for another members of any team they are on, and 9% somewhat agreed. Ninety-one percent (91%) strongly agreed they know how to be a good team member, and 99% somewhat agreed. Sixty-four percent (64%) strongly agreed they know a lot about what it takes to be a good leader, 18% somewhat agreed, and 18% were neutral. Sixty-four percent (64%) strongly agreed they know what it takes to help a team accomplish its task, 27% somewhat agreed, and 9% were neutral. Fifty-five percent (55%) strongly agreed they are confident in their ability to influence a team they lead, and 45% somewhat agreed. Eighty-two percent (82%) strongly agreed they know how to encourage good team performance, and 18% were neutral. Eighty-two percent (82%) strongly agreed they are able to allow other team members to contribute to the task when leading a team, and 18% somewhat agreed. Forty-five percent (45%) strongly agreed they can train or supervise students and/or technicians in the laboratory, 18% somewhat agreed, 18% were neutral, 9% somewhat disagreed and 9% strongly disagreed.

Table 9 Scientific Leadership 2015 Pre-Survey Results *(n= 11)*

	Question	SA	SWA	N	SWD	SD
Q7	I know how to cooperate effectively as a member of a team	91%	9%			
Q8	I find it easy to follow instructions or take orders from others	55%	36%	9%		
Q9	I have high confidence in my ability to function as part of a team	73%	27%			
Q10	I can provide strong support for other members of any team that I am on	91%	9%			
Q11	I know how to be a good team member	91%	9%			
Q12	I know a lot about what it takes to be a good leader	64%	18%	18%		

Q13	I know what it takes to help a team accomplish its task	64%	27%	9%		
Q14	I am confident of my ability to influence a team I lead	55%	45%			
Q15	I know how to encourage good team performance	82%		18%		
Q16	I am able to allow other team members to contribute to the task when leading a team	82%	18%			
Q17	I can train or supervise students and/or technicians in the laboratory	45%	18%	18%	9%	9%

Strongly Agree (SA), Somewhat Agree (SWA), Neutral (N), Somewhat Disagree (SWD) or Strongly Disagree (SD)

2015 Post-survey Results

Eight (67%) out of 12 students participated in the *post*-survey and provided feedback on their experience.

General Self-Efficacy Post-Survey Results

Participants indicated: Strongly Agree (SA), Somewhat Agree (SWA), Neutral (N), Somewhat Disagree (SWD) or Strongly Disagree (SD) to the statements in Table 10. Post-survey results reveal 88% strongly agreed they are confident working with others to investigate a research problem, and 13% were neutral. All survey participants (100%) strongly agreed they are confident discussing research with other students; and 100% strongly agreed they are confident discussing research with graduate students. Eighty-eight percent (88%) strongly agreed they are confident discussing research with professors while 13% felt somewhat confident discussing research with professors. All survey participants (100%) strongly agreed they are confident discussing research at a professional meeting or conference.

Table 10 General Self-Efficacy *Post*-Survey Results *(n=8)*

	I can:	SA	SWA	N	SWD	SD
Q1	Work with others to investigate a research problem	88%		13%		
Q2	Discuss research with other students	100.00%				
Q3	Discuss research with graduate students	100.00%				
Q4	Discuss research with professors	88%	13%			
Q5	Discuss research at a professional meeting or conference	100%				

Strongly Agree (SA), Somewhat Agree (SWA), Neutral (N), Somewhat Disagree (SWD) or Strongly Disagree (SD)

Research Skills and Knowledge Post-Survey Results

Post research skills and knowledge results are shown in Table 11. Participants were asked to indicate how much they know about working collaboratively with others using a 5 point scale with 5 being “a great deal,” 4 being “somewhat a great deal,” 3 being “neutral” 2 being “ knowing something but not a lot,” and 1 being “nothing at all. Post-survey responses reveal 75% indicated they know a great deal, 13% indicated they know somewhat a great deal, and 13% were neutral.

Table 11 Post Research Skills and Knowledge Results *(n=8)*

Participants were asked to indicate how much they know about working collaboratively with others		A great deal	Somewhat a great deal	Neutra l	Some-thing but not a lot	Nothing at all
		Post (n=8)	Post (n=8)	Post (n=8)	Post (n=8)	Post (n=8)
Q6	Working collaboratively with others	75%	13%	13%		

Scientific Leadership Post-Survey Results

Scientific leadership post survey results are shown in Table 12. All survey participants (100%) strongly agreed they know how to cooperate effectively as a member of a team. Sixty-three percent (63%) strongly agreed they find it easy to follow instructions or take orders from others, 25% somewhat agreed, and 13% indicated they are neutral in following instructions or taking orders from others. Sixty-three percent (63%) strongly agreed they have high confidence in their ability to function as part of a team, 25% somewhat agreed, and 13%

Table 12 Scientific Leadership Post Survey Results *(n= 8)*

		SA	SWA	N	SWD	SD
Q7	I know how to cooperate effectively as a member of a team	100%				
Q8	I find it easy to follow instructions or take orders from others	63%	25%	13%		
Q9	I have high confidence in my ability to function as part of a team	63%	38%			
Q10	I can provide strong support for other members of any team that I am on	100%				
Q11	I know how to be a good team member	100%				
Q12	I know a lot about what it takes to be a good leader	75%	25%			
Q13	I know what it takes to help a team accomplish its task	75%	25%			
Q14	I am confident of my ability to influence a team I lead	63%	38%			
Q15	I know how to encourage good team performance	50%	50%			

Q16	I am able to allow other team members to contribute to the task when leading a team	75%	13%	13%		
Q17	I can train or supervise students and/or technicians in the laboratory	63%	13%	25%		

Strongly Agree (SA), Somewhat Agree (SWA), Neutral (N), Somewhat Disagree (SWD) or Strongly Disagree (SD)

indicated they are neutral. All participants (100%) strongly agreed they can provide strong support for other members of any team that they are on. All participants (100%) strongly agreed they know how to be a good team member. Seventy-five percent (75%) strongly agreed they know a lot about what it takes to be a good leader, 25% somewhat agreed they know a lot about what it takes to be a good leader. Seventy-five percent (75%) strongly agreed they know what it takes to help a team accomplish its task, 25% somewhat agreed they know what it takes to help a team accomplish its task. Sixty-three percent (63%) strongly agreed they are confident of their ability to influence a team they lead, and 38% somewhat agreed they are confident of their ability to influence a team they lead. Fifty percent (50%) strongly agreed they know how to encourage good team performance, 50% somewhat agreed they know how to encourage good team performance. Seventy-five percent (75%) strongly agreed they are able to allow other team members to contribute to the task when leading a team, 3% somewhat agreed and 13% were neutral regarding their ability to allow other team members to contribute to the task when leading a team. Sixty-three percent (63%) strongly agreed they can train or supervise students and/or technicians in the laboratory; 13% somewhat agreed and 25% were neutral in their confidence in their ability to train or supervise students and/or technicians in the laboratory.

2015 Pre- and Post-Survey Results

This sections provides a comparative view of pre- and post-survey results from the 2015 VisREU cohorts. Tables 13, 14, and 15 shows pre- and post- General Self-Efficacy, Research Skills and Knowledge and Scientific Leadership Results, respectively. Questions for General Self-Efficacy (Q1-Q5), Research Skills and Knowledge (Q6) and Scientific Leadership (Q7-Q17) are provided in Tables 5, 6 and 7, respectively.

Table 13 Pre- and Post- General Self-Efficacy Results

	SA		SWA		N		SWD		SD	
	Pre (n=11)	Post (n=8)	Pre (n=11)	Post (n=8)	Pre (n=11)	Post (n=8)	Pre (n=11)	Post (n=8)	Pre (n=11)	Post (n=8)
Q1	45%	88%	55%			13%				
Q2	54%	100%	45%							
Q3	36%	100%	45%		18%					
Q4	36%	88%	55%	13%	9%					
Q5	45%	100%	27%		18%		9%			

Strongly Agree (SA), Somewhat Agree (SWA), Neutral (N), Somewhat Disagree (SWD) or Strongly Disagree (SD)

Table 14 Pre- and Post- Research Skills and Knowledge Results

	A Great Deal		Somewhat a Great Deal		Neutral		Some But Not a Lot		Not at All	
	Pre (n=11)	Post (n=8)	Pre (n=11)	Post (n=8)	Pre (n=11)	Post (n=8)	Pre (n=11)	Post (n=8)	Pre (n=11)	Post (n=8)
Q6	55%	75%	45%	13%		13%				

Table 15 Pre- and Post-Scientific Leadership Results

	SA		SWA		N		SWD		SD	
	Pre (n=11)	Post (n=8)	Pre (n=11)	Post (n=8)	Pre (n=11)	Post (n=8)	Pre (n=11)	Post (n=8)	Pre (n=11)	Post (n=8)
Q7	91%	100%	9%							
Q8	55%	63%	36%	25%	9%	3%				
Q9	73%	63%	27%	38%						
Q10	91%	100%	9%							
Q11	91%	100%	9%							
Q12	64%	75%	18%	25%	18%					
Q13	64%	75%	27%	25%	9%					
Q14	55%	3%	45%	38%						
Q15	82%	50%		50%	18%					
Q16	81%	75%	18%	13%		13%				
Q17	45%	63%	18%	13%	18%	25%	9%		9%	

Strongly Agree (SA), Somewhat Agree (SWA), Neutral (N), Somewhat Disagree (SWD) or Strongly Disagree (SD)

DISCUSSION

We saw an increase in general self-efficacy among the surveyed in their confidence to work with others to investigate a research problem (Q1), discuss research with other students (Q2), with graduate students (Q3) and with professors (Q4). There was improvement by all participants (100%) in their confidence to discuss research at a professional meeting or conference (Q5). We saw students who reported being neutral regarding how much they know about working collaboratively with others in the pre-survey, reported knowing a more about working collaboratively with others in the post-survey (Q6). We saw 9.09% of students strongly agreeing to knowing how to cooperate effectively as a member of a team (Q7), being willing to provide strong support for other members of any team they are on (Q10), and knowing how to be a good team member (Q11). There was an increase in the number of students who strongly agree they find it easy to follow instructions or take orders from others, a decrease in the number of students who somewhat agree, and an increase in the number of students who found themselves to be neutral to taking orders from others (Q8). There was a decrease in the number of students who strongly agree they have high confidence in their ability to function as part of a team; there was an increase in the number of students who somewhat agree they have high confidence in their ability to function as part of a team (Q9). We suspect after learning visualization is a process and consequently the stages of that process—students reassessed what they thought they knew about data visualization at the start of the program, resulting in more students somewhat agreeing that they had high confidence in their ability to function as part of a team. We saw an increase in students strongly agreeing and somewhat agreeing that they know a lot about what it takes to be a good leader, and a decrease in the number of students who reported being neutral in the pre-survey (Q12). There was an increase in the number of students strongly agreeing they know what it takes to help a team accomplish its task (Q13). We saw an increase in the number of students who strongly agree they are confident in their ability to influence a team they lead and a decrease in the number of student who somewhat agree they are confident in their ability to influence a team they lead (Q14). We saw a decrease in the number of students who strongly agree they know how to encourage good team performance (Q15). Students base their confidence in their ability to work in a collaborative environment on their experience with being a member of a class group project. The VisREU experience provided a more structured approach to collaboration which included accountability of all members and a view of the bigger research project to which each member contributed to. It is conceivable to believe this may have had an impact on the post-survey response to Q15. We saw a decrease in the number of students who strongly agree they are able to allow other team members to contribute to the task when they are leading a team (Q16). This suggests this is a skill that is learned with experience. We saw an increase in the number of students who strongly agree they can train or supervise students and/or technicians in the laboratory (Q17).

Project Outcomes

Learning and research objectives of the VisREU Site mirrored learning objectives for undergraduate research program cited in the literature above (see Introduction). Satisfactory completion of learning outcomes and research objectives for the VisREU Site were assessed through student presentation and written research paper detailing their summer work and results. All students were required to give a midterm and final presentation, at the half-way mark and at the end of the program, respectively.

Another unique feature of the VisREU Site was the participation of both cohorts in the student program of the 2014 and 2015 Extreme Science Engineering Discovery Environment (XSEDE) conferences. Traditionally, only a few students make significant progress to present their work at a conference, and usually conference participation occurs after the program concludes and the student has returned to their home institutions. Additional funding was secured by the PI to fund travel and student participation in the conferences as part of the summer program. For many students, the XSEDE Conference was their first experience attending a conference, and presenting their research findings to a professional audience. All students were encouraged to submit an abstract detailing their summer research to the XSEDE Student track. If a student's abstract was accepted to the conference, their presentation of results in the XSEDE student track served as one measure of satisfactory completion of learning and research objectives. Due to the nature of research, there were some projects that experienced slow starts resulting in the student not having enough data/results in time to submit abstracts to the conference; however, most students did satisfy the learning and research objectives of the program. Fifteen students (out of 22, from the combined cohorts) participated in student poster sessions at XSEDE.

RECOMMENDATIONS

The VisREU Site continued to improve and build on the success of the previous year. Student feedback helped to shape promising practices for future implementations. Promising practices from the 2014/2015 VisREU Site experience for research methods, student presentations, faculty presentations, and student mentoring are detailed below.

Research Methods

Students were required to complete the research and ethics training within the first week of the program. The online training is part of the Collaborative Institutional Training Initiative (CITI) provided by the University of Miami. Faculty research mentors were made aware of this requirement and was relied upon to reinforce this guideline. Upon completion of CITI Training, students provided a copy of the completion report to the program coordinator and to their faculty research mentor. Students were given access to research data after providing proof of completion of the CITI training.

During the first year of the VisREU Site, research faculty were recruited to provide a lecture to the cohort on research methods. The volume of information covered was overwhelming for first time student researchers. The following year (2015) a research methods track was included in the summer research curriculum.

Promising practice: Instead of presenting one long lecture on research methods a mini-course on research methods was developed by REU Site staff, and presented over the first three weeks of the program. All students were required to attend. This allowed for a gradual and gentle introduction to the many aspects of conducting and reporting research.

Student Presentations

Students were required to give a minimum of two presentations as part of the REU program: a midterm power point presentation and a final poster presentation. Additional supplemental funding was secured to fund five students for the first two years of the VisREU Site to participate in the student poster competition at Extreme Science and Engineering Discovery Environment (XSEDE) annual conferences. Usually, students attend conferences after their participation in a REU experience. Students were made aware of the funding opportunity and used the possibility of going to a national conference to motivate their work.

Promising practice: Funding to support student participation at a conference or in a venue that simulates a conference-like atmosphere increased student confidence in their work, gave students opportunities to present and tailor their work to fit various audiences.

Faculty Presentations

Research faculty were asked to give a one-time presentation to the REU Cohort about their research. Typically faculty are free to talk about any research project they choose to share.

Promising practice: In year two (2015), faculty were asked to include in their presentation the contribution the student was making to the research project and specifically state the importance of the student's work. This gave the entire cohort exposure to a broad range of research and they were able to see the significance of their work in a much larger context.

Student Mentoring

Students were asked to provide feedback after each program event. Based on feedback from the 2014 cohort, weekly group mentoring was incorporated into the 2015 summer research curriculum.

Promising practice: Group mentoring was scheduled, typically mid-week, after lab time and meetings with research teams and mentors. During this time students participated in a Mad-Glad-Sad Exercise (professional communication, Stratos Efstathiadis, NYU Medical Center; 2015 MOR Leadership Cohort) where each student stated one thing they were mad about, one thing they were glad about, and one thing they were sad about as these things related to the summer program. This exercise, although looked upon as being silly initially by the cohort, allowed students to voice their concerns and comments in a comfortable space. Group mentoring complemented individual mentoring sessions.

CONCLUSIONS

Visualization plays an important role in all levels of scholarship. At the time of its funding, the VisREU Site was the only REU Site where visualization is the primary research focus. Wherever there is data, regardless of major, there will be a need to visualize it. Visualization as a tool can be used to show commonality between disciplines and among research groups. An area of study with such far reaching impact should be incorporated not only into research experiences of undergraduates, but also in all academic fields as a tool for analysis, discovery and collaboration.

In this work the collaborative aspects of the VisREU Site were examined. Findings suggest the VisREU Site was effective in enabling students to work on their collaborative and leadership skills. There were a few areas where student confidence dipped; however, it is plausible the decrease in confidence was due to learning, for the first time, that visualization is about gaining insight, not about creating a pretty picture. Most, if not all, VisREU participants were unware data visualization is a process and the nature of true collaboration across disciplines, backgrounds and ethnicities prior to participating in the VisREU Experience. Clearly understanding the impact of data visualization capacity building, its ability to gain insight into complex data and foster collaborations are 21st century skills that will prepare students for the data driven workforce. As data continues to grow, so does the need for interdisciplinary solutions. Visualization is a common thread that can and should be utilized to gain insight and enable creative, innovative solutions that are diverse and inclusive. Students entering the workforce must know how to work both independently and in collaborative environments. They must be open and willing to lead from behind when needed by respecting the ideas of others, being able to take instructions and constructive feedback from others and by allowing others to contribute to solutions.

In addition to the collaborative findings, the self-efficacy measure is viewed as students having the ability and confidence in their learning of a new field: data visualization; applying what they learned to research, and confidently discussing their findings with their student colleagues, graduate students, and research mentors and at professional meetings and conferences. The findings suggest strong student self-efficacy can enhance student learning.

Evidence of the importance of visualization can be seen in the role visualization continues to play in informed decision making [1-4], data analysis [5], explanations of complex data sets [6-8], detection of trends and patterns [9], and storytelling [10-12]. The need to diversify a field with such far-reaching influence is imperative [13]. Visualization is the process of transforming raw, complex data into a visual representation that provides insight. In order to prepare the next generation of researchers and scientists to make transformative and innovative discoveries in a data-driven world, exposure to the process, tools and techniques of data visualization must begin early. As these findings suggest, the ability to work in collaborative settings impacts student learning, progress and success.

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