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An ET-CURE Pilot Project Supporting Undergraduate Training in Cancer Research, Emerging Technology, and Health Disparities

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Abstract

The National Cancer Institute's Center to Reduce Cancer Health Disparities has created pilot training opportunities under the "Continuing Umbrella of Research Experiences" (CURE) program that focus on emerging technologies (ET). In this pilot project, an eighteen month cancer biology research internship was reinforced with: instruction in an emerging technology (proteomics), a transition from the undergraduate laboratory to a research setting, education in cancer health disparities, and community outreach activities. A major goal was to provide underrepresented undergraduates with hands-on research experiences that are rarely encountered at the undergraduate level, including mentoring, research presentations, and participation in local and national meetings. These opportunities provided education and career development for the undergraduates, and they have given each student the opportunity to transition from learning to sharing their knowledge and from being mentored to mentoring others. Here, we present the concepts, curriculum, infrastructure, and challenges for this training program along with evaluations by both the students and their mentors.

MeSH Terms

Cancer Research; Proteomics; Undergraduate Training; Community Outreach

Introduction

The lack of scientists from underrepresented racial/ethnic minorities contributes to disparities in both education and health care; conversely, increases in the diversity of racial and ethnic backgrounds would provide new perspectives on cancer research and enable development of culturally competent outreach and education initiatives [1–9]. Research training programs for undergraduates, which have increased significantly in the last decade, are being used to excite and equip the next generation of cancer researchers [6, 10]. These programs can be designed to benefit the entire community, including the students, the mentors, and the institution. Students gain research experience, presentation skills, peer-to-peer interactions, networking opportunities, professional development, and stipend support; research mentors have the opportunity to increase their teaching experience, receive student

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feedback that may produce new perspectives on their research, and add a team member to their laboratory for assistance with projects [2, 5–6, 9–11]. The research institute benefits by improving its reputation for training and education [2].

Moffitt currently supports two such research internships for undergraduates. The Summer Program for the Advancement of Research Knowledge (SPARK) provides full-time research internships for undergraduates over 10 week periods in the summer. The Leaders In New Knowledge (LINK) program provides year round research internships for undergraduate students from underrepresented backgrounds; they work in the laboratory part-time through the academic year and full-time during the summer. Supported by funding from the Emerging Technologies-Continuing Umbrella of Research Experiences (ET-CURE) program administered by the National Cancer Institute Center to Reduce Cancer Health Disparities (CRCHD), the **L**eaders **I**n **N**ew **K**nowledge-**E**merging **T**echnologies (LINK-ET) pilot project was created to build on the well-established LINK program as a model. In addition to the internship in cancer research, the LINK-ET students were trained in an emerging technology (proteomics), educated about health disparities, and participated in community outreach activities. Each of these additional components significantly enhanced the experiences for the students.

Instruction in emerging technologies, such as proteomics, can be difficult because most undergraduates have not been exposed to even the most basic concepts of these new fields. On the other end of the spectrum, the research groups that define the cutting edge often may not participate in educational programs. Furthermore, the cost of the liquid chromatography and mass spectrometry instrumentation used in proteomics is prohibitive for most undergraduate institutions. Existing literature in chemical education provided individual example experiments in mass spectrometry [12–19] and proteomics [20–22]; these existing laboratory exercises could be combined with additional materials to develop a cohesive strategy for instruction. In addition to the development of a one semester curriculum, this element of the training would also need to support the transition from the undergraduate laboratory to a cancer research setting.

To complement the training in emerging technologies, the students would benefit greatly from understanding their role and future opportunities as scientists from underrepresented backgrounds. Education in cancer health disparities and participation in community outreach activities are typically geared to graduate students and post-doctoral fellows, particularly those in public health fields, rather than to undergraduates. Therefore, specific training materials would need to be developed. The inclusion of outreach activities will provide the students with reinforcement of the importance of their interest in science and health care and enable greater connection with their community. These efforts would also need to be balanced with the requirements of the research internship and the instruction in proteomics.

Here, we describe aspects of the pilot LINK-ET program, which combined didactic and hands-on training, mentoring, networking, and outreach in a collaborative model, as shown in Figure 1A. The infrastructure required for student recruitment and curriculum development are included along with preliminary outcomes and potential improvements that could be implemented in the design of new programs.

Methods

Recruitment of a Project Coordinator

A postdoctoral fellow (DW) was hired to assist in the development of an appropriate proteomics curriculum, serve as an initial contact and advocate for the students, and support the organization of training and mentoring activities. Qualifications included past participation in research internships targeted to underrepresented undergraduate students, completion of PhD in biochemistry with an emphasis in emerging technologies, and postdoctoral science education training.

Recruitment of Students

Advertisements and applications were dispersed to local colleges and universities using contacts at Honors Colleges, academic science departments, and relevant student organizations. Materials were also made available on the institution's website. Students (n = 4) needed to meet certain requirements to qualify for the program. First, they had to be considered underrepresented. The definition of underrepresentation was drawn from the National Science Foundation and the CURE program, and it extends beyond racial and ethnic groups (*e.g.* African-American, Hispanic, Native American, and Middle Eastern) to include individuals who are disabled, in the first generation of their family to attend a college or university, from low-income families, and/or raised in rural communities [3, 9]. Each student must maintain a minimum GPA of 3.5, provide two recommendation letters, and compose a personal statement expressing their interest in cancer research. Sophomores and juniors that had successfully completed the first challenging course in their major (*e.g.* organic chemistry or cell biology) were selected, ensuring both the students' capability to master the concepts required for the research internship and their commitment to continuing their education in basic science.

Program Development

LINK-ET was structured based on the LINK program established in 1999, which creates internship opportunities for qualified high school and undergraduate students who have both interest and aptitude in science. Students are placed in research laboratories and then taught and mentored by lab members and their principal investigator, as well as the faculty and staff supervising the LINK program. Building on this infrastructure, LINK-ET incorporated additional training and opportunities as described in the following paragraphs.

Mentoring

Mentoring and coaching were also important aspects of this training program [3]; both the grooming model and the networking model were used. The traditional grooming model pairs a mentor with a protégé to enhance their possibility of success, while the networking model uses a non-hierarchical connections among a number of people to support the student [12]. During the training in proteomics, students had one-on-one meetings with the faculty director, Proteomics staff, and the project coordinator. Supportive relationships offered opportunities for students to explore career paths, to test ideas, and to broaden their perspectives. Mentoring during the research internship occurred via interactions with the research group and the principal investigator, adding to the supportive relationships receiving during their training to provide different professional perspectives. Additional mentoring opportunities were more informal, including lunches and discussions at conferences.

Training in Proteomics

The curriculum and laboratory exercises in proteomics were developed by the faculty core director, core staff scientist, and the LINK-ET program coordinator. The Proteomics Core and the Koomen laboratory had previously hosted SPARK interns and provided training for graduate students, post-doctoral fellows, clinical fellows, and staff. These prior experiences and the existing literature in chemical education were used to develop lectures and laboratory exercises for a one semester (16 week) curriculum that was provided to the students at the beginning of the program, as shown in Figure 1B. The students participated in didactic training for 1–2 hours each week. The students were also provided with relevant review articles and primary research articles from peer reviewed journals. Students were required to discuss the reading assignments and laboratory concerns using a journal club format. Concepts in mass spectrometry and proteomics were covered in five different modules as shown in Table 1.

Each complementary laboratory assignment reinforced the lecture and provided hands-on experience with proteomics techniques and instrumentation; each experiment was designed such that the students would complete them in 8–10 hours each week. The time needed to be budgeted in blocks with a minimum of 4 hours each. As the exercises increased in difficulty, additional time was required for project completion. Students worked in pairs with close supervision, mimicking the undergraduate laboratory environment. However, they also completed certain tasks independently in order to prepare them for working in a research group setting where the ability to interact as an independent team member is essential.

Evaluation of the course materials and students' knowledge was accomplished through quizzes, surveys, and comparison against results obtained by Proteomics Core staff. The students were quizzed on the materials from the first two modules after two months of instruction. A second quiz on course materials was administered six months after the completion of the lecture series to gauge their retention of the concepts. Students were also required to write lab reports highlighting the results of their lab assignments after completion of module 2 and module 4, which were formatted similar to scientific manuscripts with an abstract, introduction, methods, results and discussion, as well as conclusions. Students' confidence in the knowledge and laboratory experience was probed by a survey administered six months after completion of the training.

Research Internships

Upon completion of the training segment of LINK-ET, students were placed in different research groups to use their experience in proteomics for collaborative projects. The matching of students and mentors was a careful and a deliberate process based on research interests, lab group dynamics, and personality. Each student was paired with a graduate student, postdoctoral fellow, or PhD-level scientist to ensure that a hands-on mentor would be available in the laboratory. They were also instructed in techniques in cancer biology and received additional mentoring by other faculty and staff. This instruction was expected to develop research skills, critical thinking, and problem solving using the different resources available in each laboratory. Another primary focus was to gain knowledge in a particular research area that required collaborative involvement with proteomics. These research areas included: phosphoproteomic analysis of signaling pathways in melanoma, protein expression *in vivo* in the tumor microenvironment using mouse models, proteomic assays to assess SRC family kinases, and evaluation of lung cancer therapy in preclinical models.

Education in Health Disparities and Participation in Outreach

The students engaged in a group discussion with presentations by post-doctoral fellows focused on community outreach and education. They also attended the 7th Biennial Cancer, Culture and Literacy conference hosted by Moffitt and "The Science of Cancer Health Disparities" (2010, Miami, FL) sponsored by the American Association for Cancer Research. These opportunities fostered students' awareness and appreciation for cultural competency.

Outreach activities related to cancer, health, science and education help to develop a deeper understanding of the importance of cancer research. Events were organized by partnering with other Moffitt faculty and community programs; the LINK-ET students were provided with opportunities to volunteer at health fairs and communicate their research to community members. For example, CURE trainees interacted with members of the Tampa Bay Community Cancer Network [23, 24], which is an NCI-funded regional community network program center initiative to reduce cancer health disparities among medically underserved populations. Students promoted cancer prevention, healthy lifestyle choices, and science education at local health and education fairs. Serving as role models, the students translated their research experiences to presentations for and conversations with community members, providing information to children, teenagers, and adults in an engaging informal environment.

Collaboration and Teamwork

Collaborations permit interdisciplinary research approaches to address complex questions in cancer research; teamwork develops consideration of others and the ability to work in a group, which is vital to conducting research [3, 7, 25]. As part of their research internship, the students were trained in proteomics and placed in cancer biology labs to work on projects that relied on proteomics analysis. Because of the team science approach required for most, if not all, emerging technologies, the students also worked with other scientists including analytical chemists, bioinformaticians, biostatisticians, cancer biologists, and physicians.

Networking

Networking provides opportunities to meet potential mentors and collaborators [6, 8–9]. These interactions also build communication skills. The students attended research group meetings and Moffitt seminars, where they also had the ability to interact with the speakers and other members of the audience. They participated in professional and scientific career development with guest speakers and career counselors during monthly LINK/LINK-ET program meetings, which also enabled the development of supportive peer-to-peer networking. Attendance at local and national meetings was also a critical component of networking, because each student could meet other researchers at their institution, prominent figures in the research community, and members of the NCI.

Measurements

Measurements examined the quality of the research training experience, assessed the performance of the student, and evaluated programmatic accomplishments. The classroom and laboratory performance of each student was assessed via quizzes and lab reports, as described above. Process and outcome evaluations were developed to assess the proteomics training and the research internship as well as the professional development opportunities provided by LINK-ET. Surveys are available in portable document format in the Supplementary Material. Student progress was also measured by traditional metrics, including project completion, data quality, and presentations (in both oral and poster formats).

A baseline assessment was given to each student during their initial orientation to determine their knowledge of proteomics, their level of professional development (including Curriculum Vita, prior mentoring, networking, career goals, etc) community involvement, and interests outside of science. An interim survey with both Likert scale and free response questions were given to the students at the end of their first semester (prior to beginning the research internship) in order to receive feedback on their training in proteomics and the professional development opportunities. A written curriculum evaluation was disseminated in person to examine the students' confidence in their knowledge of proteomics and to assess changes in goals and attitudes toward staying in scientific careers after six months of involvement in their research. Assessments during the research internship occurred continuously via tracking of the student's participation using meetings with program faculty and staff as well as their research presentations. A written survey enabled the mentors to assess their interaction with Project LINK-ET program and its staff and to formally assess student performance after approximately one year of interaction in their laboratory.

Results

Baseline Assessment

Respondents described their experiences in science classes, laboratories, research, academic involvement, professional development, and community outreach. Two of the students had previous research training, but none of them had any prior exposure to proteomics. All of them expected this program to provide research experience and increase their involvement with community outreach. One respondent expected some networking opportunities to refine his career goals. Each student planned to pursue advanced degrees (1 PhD, 2 MD/PhD, and 1 MD). This initial survey enabled further evaluation and evolution of the course design and curriculum (see Table 1).

Proteomics Curriculum and Student Evaluation

Lectures were prepared using PowerPoint; slides were also given as handouts to the students at each meeting. Laboratory exercises were designed and tested by Proteomics Core staff. The concepts behind each experiment were discussed in the lecture, and handouts were given describing the procedures. In order to transition to more independent research, each student worked alone and with a lab partner once each week. Data from the laboratory exercises were also discussed during the lectures. The immersive nature of the training (2 hours of lecture and 8 hours of lab) was effective in training students with no prior experience in proteomics. Quizzes were given after module 2 and module 5 to assess retention of basic concepts in proteomics. Although student performance was measured, the main purpose of these quizzes was to assess areas in which more teaching was required. Therefore, quizzes were take-home and open-book format (as an example, Quiz I has been included in the Supplementary Material. As an example, the students were asked to define proteomics and what are the key analytical steps in sample preparation. All responses were discussed at the next class period to reinforce retention of the information. When surveyed, students thought that more frequent assessment would have been helpful, so we found it useful to start every class period with an in depth discussion of these questions.

Translation of didactic training into practice was evaluated using two lab reports, which also provided the students with experience in scientific writing. To explain, their first lab report was a short communications, structured in a journal format, (abstract, methods and materials, results, discussion, conclusions and references). This report described their first set of experiments about key proteomics topics (e.g., mass spectrometry analysis of standard peptides, digests of protein standards, and analysis of salivary proteins with mass spectrometry) For the second lab report, the students were asked to draft a full manuscript based on the style and substance of examples provided from the literature in proteomics; this lab report included methods and results from analysis of protein digests with different fractionation techniques and liquid chromatography-tandem mass spectrometry peptide sequencing. Additional information and course materials are available upon request.

Students' Interim Evaluation of the LINK-ET Program

Feedback received from the interim evaluation indicated that LINK-ET was successful in providing a research training program that supported the career development of the participants and sparked their interest in research. When asked if project LINK-ET had assisted with meeting their career goals, all students responded positively. Each of the students indicated an increased interest in continuing to participate in research. The students indicated that weekly institutional seminars, group meetings, proteomics staff meetings, and journal articles have all contributed to their learning. They also articulated that the community outreach and volunteer opportunities helped them realize that their research and their success have value in the community. Students were gratified that they made a difference by helping to provide health education and seeing the community's response to their involvement in cancer research. Students stated that they were very satisfied with the organization of the program and the mentoring; furthermore, they would recommend the program to other students.

The use of training segments with a classroom and laboratory format can be directly compared against the existing LINK program, in which the students begin with their research internship after minimal orientation. LINK-ET students felt comfortable entering the research internship after the training. In addition, the small group format brought cohesiveness to the group; the fact that they had all received the same training in proteomics also meant that they could assist each other with experiments.

Curriculum Evaluation

Feedback from the curriculum evaluation was positive indicating that the didactic and hands-on training helped prepare the students for independent research. As shown in Table 2, the outcome evaluation examined their feedback on the format of the lectures and labs, their conceptual understanding of proteomics, their confidence in performing experiments independently, and their motivation to pursue a scientific career.

The students felt the classroom structure and experience met or exceeded their expectations. It is important to note that all of the students indicated that the level of interaction with the instructors exceeded their expectations (scoring 5/5 each time). Results also indicated that the hands-on laboratory experiences reinforced the concepts discussed during the lectures. As an example, one student commented that, "The class lecture went into great detail about the instrumentation and the purpose of the project. When I got to the laboratory, I already knew the instrument's role and what the experiment will accomplish." The structure and experiences met or exceeded their expectations, although challenges were noted with limited access to instruments on occasion and the need for expanded time for some lab exercises. Free response answers emphasized the positive aspects of working in a professional environment, learning new techniques, and being trained in ET.

Students were also asked to evaluate their understanding of the course materials and their confidence in their ability to independently complete experiments. Students gave high scores for their retention of knowledge and confidence in completing experiments for earlier modules, which focused on mass spectrometry and peptide sequencing with tandem mass spectrometry (see Table 2). All students gave decreasing scores for later modules in the Proteomics training that were more complex and built on the knowledge obtained earlier in the curriculum. Notably, the lowest scores were given for quantification, which the students completed during their transition to the research internship. Because each of the students would use quantitative experiments in their research internship, no lab exercise had been prepared. In part, this situation was designed to challenge the students. Free responses indicated that the training was effective in preparing each student to conduct proteomic analyses; the students expressed appreciation for both the didactic and the hands-on training. As the students gained more research experience, most of their interactions with proteomics staff involved coaching and challenging the students to draw on their training, rather than teaching them.

Overall, the program had increased the students' confidence in their analytical skills and research acumen. As examples, feedback included: "The training prepared me for running my own samples," "I was more confident operating the instruments," and "I was able to understand laboratory procedures more clearly." Students noted that they were very comfortable when returning to the undergraduate laboratory environment as part of their classwork and appreciated "working in a professional environment," because they felt better prepared for other laboratory exercises. The students agreed that their interest in cancer research, emerging technologies (including proteomics), and scientific careers had increased due to their participation in the program, as shown in Table 2.

Evaluation of Student Performance During the Research Internship

For evaluation of the students' performance during the research internship, the following criteria were taken into account: independence in the laboratory, presentation of data at local and national conferences, and contribution to publications. The students have been able to make multiple presentations thus far as a result of this program; in most cases, these opportunities would not be available until the graduate level. Each student made a five minute oral presentation using PowerPoint slides at the Moffitt Undergraduate Research Symposium; the audience consisted of their families, co-workers, and other faculty and staff in the Moffitt community. Coaching the students with practice presentations in the research group meetings and Proteomics Staff meeting enabled the students to reorganize their presentations, improve their communication skills, and reduce their anxiety of giving a talk to a large audience. In addition to this oral presentation, the students have also gained experience with poster presentations. Each student presented a poster at the American Association of Cancer Research (AACR) conference titled "The Science of Cancer Health Disparities." Again, review and editing of the poster materials by multiple faculty members and practice presentations enabled the students to refine their figures and messages to the audience. Observers frequently remarked about their professionalism and complemented them as producing graduate-level work. Additional local poster presentations have been made at Moffitt events and the USF Health Research Symposium; furthermore, one student presented in an undergraduate poster session at the AACR Annual Meeting (2011, Orlando) and another at the Florida-Georgia Louis Stokes Alliances for Minority Participation (FGLSAMP) Annual Research Exposition (2011, Jacksonville, FL). While none of these projects has yet been published, we do expect that the students will contribute sufficiently to their projects to warrant inclusion in authorship.

Mentors' Evaluations of the Program

In addition to the metrics described in the previous paragraph, both the students and the LINK-ET program were evaluated by the mentors after the students had been working in the research internship for approximately one year. Results from the mentor evaluation displayed satisfaction with their experience during the program. Mentors noted that the most satisfying aspects included the enthusiasm of the students, their increases in confidence and productivity in the laboratory, and the ability to provide advice and career counseling; one mentor commented: "The most enjoyable aspect of mentorship in the LINK-ET program remains the contribution we make to the life and education of these intelligent, goal-driven, young undergraduates." In addition, mentors also discussed the fact that some of these projects could only be undertaken because of the placement of a student that was co-trained in proteomics and able to work on the collaborative project. In terms of the overall program evaluation, one mentor commented: "I believe that the LINK-ET project is an excellent program facilitating direct experience and scientific mentoring to undergraduate students. Undergraduates are exposed to scientific thought and the "real life" inner-workings of cancer research. The program affords the opportunity to cultivate the future career paths of young medical science leaders of tomorrow. The program allays a well-rounded education, not limited to the lab or classroom, but also to the community. Therefore, the education creates an atmosphere for socially conscience/proactive and well-rounded individuals. Importantly, the individuals represent a group that have achieved much on their own and are likely to benefit from significant mentorship at this stage in life." Challenges included making sure that each student had sufficient guidance and resources as well as limiting expectations and having patience while working with the undergraduates, because of the number of different commitments that each student had to balance. A mentor noted the difficulty of "tempering high expectations to adapt to the level of the students, particularly when the student does very well." In other words, mentors commonly held students to the standards that would be expected for other members of their laboratories (*e.g.* graduate students, research assistants, or postdoctoral fellows), but realized that it may be difficult for undergraduates to consistently meet that level of expectation.

When asked about their level of interaction with the students, all of the mentors included one-on-one training as well as participation in lab meetings. Individual mentors had also acted as career counselors (3/4), gave personal advice (2/4), and coached the students (2/4). The mentors felt that each student had been well-matched and had integrated into the research groups at either an appropriate level or had exceeded their expectations. As an example of the feedback, one mentor noted that "The student fits in intellectually and personally. Beyond the proteomics training received at the beginning of the internship, mentors listed the following areas of instruction: use of controls, safety, cell culture, SDS-PAGE, Western blot, plasmid preparation, subcloning, scientific thought and experimental design, presentation skills, analysis of scientific literature, animal work, magnetic resonance imaging, and tumor physiology to complement the students' training in proteomics.

Mentors were asked to comment on the most important attributes for successful interactions with the students. Recommendations offered by the mentors include having patience with the students and assuring that there are enough staff members in the lab willing to provide supervision and training. All mentors (4/4) recommended participation in this program to others, but noted that the laboratory must have the proper resources to support the students (e.g. mentors recommended having at least 5 laboratory personnel that could be available to answer questions) and provide a well-defined project. Key messages imparted by the mentors directed the students to understand that research is fun, you learn best from failure, that hard work and dedication are important, and also that research is necessary to provide better treatment to cancer patients. The mentors made programmatic recommendations, which included quarterly (or even monthly) meetings to discuss the students' progress during the year, address different issues, and provide updates so that the program leaders and the mentors have similar expectations and plans for the students. They also suggested that a reward or recognition system should be in place for laboratory personnel that take an interest in the students and provide day-to-day mentoring.

Discussion

The LINK-ET program provided a research internship, which has been enhanced with a number of additional opportunities. This eighteen month undergraduate research training program at an NCI-designated Cancer Center crossed the spectrum of cancer research providing didactic and hands-on training in both emerging technology (proteomics) augmented by mentoring and coaching for professional development, and community outreach experiences. Because of the long term format of this pilot project, we were able to incorporate all of these different activities (listed in Figure 1). On the other hand, most undergraduate research training programs, like the NSF Research Experience for Undergraduates (REU) and the NIH Summer Undergraduate Research Fellowship (SURF), are usually short internships that take place in the summer (lasting six to ten weeks). The students then return to their respective universities, and may not be able to continue research because the facilities are not available on their campus. This barrier has been well-documented for UR students at minority-serving institutions [5].

Similar yearlong programs like Purdue University's Cancer Prevention Internship Program (CPIP) and the UCSD Moores Cancer Center's CURE program have provided similar activities and yielded comparable results. The CPIP included 400 hours of research during the summer and part-time work during the academic year [26]. The Moores program required an 8 week hands-on summer research training program in biochemistry/cell biology with the option to stay in the program during the academic year to work with an NIH-funded faculty mentor [27]. Both programs offered learning models that included research training, coursework, seminars, preparation for presentations, research conferences, discussion groups, networking events, and professional development. Furthermore, the CPIP offered a service learning project studying health disparities in the community. Ten undergraduates were recruited for that program with college majors in the areas of chemical engineering, applied mathematics, history, biology, and pharmacy [26]. There were a total of 82 CURE students in the Moores program over a seven year time span indicating that they also use small cohorts, which allows for one-on-one mentoring and easier organization of multiple enriching activities to develop the student participants [27]. Results from our student evaluations described increases in their awareness and understanding of cancer research, the benefits of faculty and peer mentoring, and increases interest in incorporating research into their career goals. These responses were similar to those recorded in the CPIP and the Moores program. Sixty-one percent of students from the Moores program are working towards advanced degrees in science and 36% were working in scientific research or teaching. This type of success indicates the ability of these programs to create the next generation of scientists. Because we do not have long-term tracking of the four LINK-ET students yet, these metrics require future evaluation to further judge the success of this program. Additional studies comparing the effects of long term research training programs for undergraduates versus summer internships would be useful in examining the outcomes for the students and their retention in scientific careers.

Challenges and opportunities for improvement encountered during this pilot project included the need to be flexible and patient with training undergraduates, especially considering their other commitments and heavy course loads. One challenge revealed from the results of the curriculum evaluation was the lack of availability of some instrumentation for sample analysis during the students' training. The Proteomics Core lab serves numerous investigators throughout Moffitt, so it was difficult at times to reserve the instrument time required for the students. Therefore, future training programs will need to have planned schedules of instrumentation needs. The transition from the proteomics training to the summer research internship (40 hours/week) challenged the students as they learned cancer biology techniques to support their projects. In addition, the transition into research during the fall semester (10–20 hours/week) was also difficult for some of the students, because of the students' commitments to heavy class loads and interest to continue their research projects. However, advice about time management provided students with knowledge to balance their research projects and school work.

Conclusions

Project LINK-ET incorporated several different training strategies and provided unique opportunities for four underrepresented undergraduate students. The long term format of the program provided multiple opportunities to teach the students science, involve them in the community, and mentor them in their professional career development. Because they were trained in proteomics in both didactic and hands-on laboratory settings, the students could gradually transition from structured undergraduate teaching to laboratory research in cancer biology. Developing an orientation to a research environment and gaining an appreciation of team science were also valuable outcomes of this initial phase. Because each student was placed with a different mentor, they could receive additional input and compare experiences with each other. Each mentor also then could allocate the resources required to support their student. Together, these advantages have contributed to their knowledge of science, self-confidence, and enhanced interest in scientific careers. Community outreach was a critical component to engage the students and to illustrate the importance of their successes and the ultimate link to community health and well-being.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations

LINK	Leaders in New Knowledge
ET	Emerging Technologies
CURE	Continuing Umbrella of Research Experiences
CRCHD	Center to Reduce Cancer Health Disparities
NSF	National Science Foundation
NIH	National Institutes of Health

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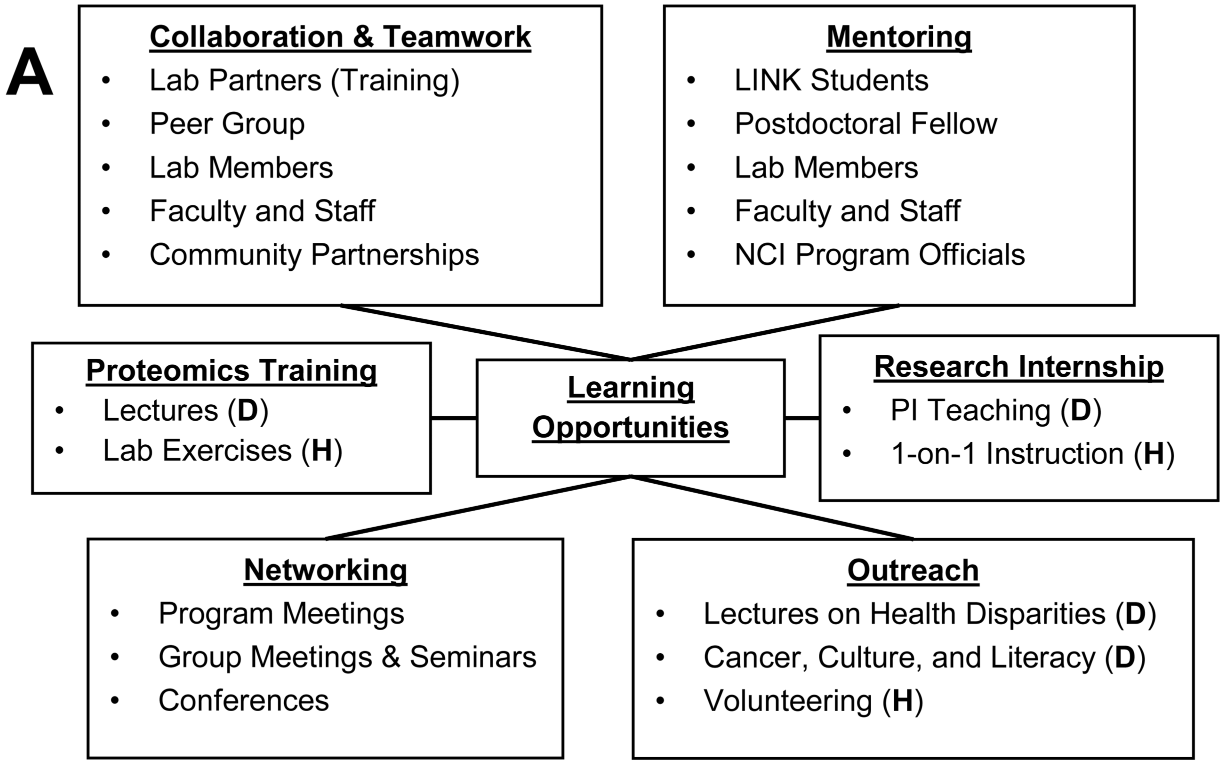

B

Semester	Spring	Summer	Fall	Spring	Summer
Months	0-4	4-7	7-11	11-15	15-18
Activity	Proteomics Training	Research Internship			
Students' Time Commitment	10 hrs/wk	40 hrs/wk	10-15 hrs/wk	10-15 hrs/wk	40 hrs/wk

Baseline Student Survey | Interim Program Evaluation | Curriculum Evaluation | Mentor Survey | Student Exit Survey

Figure 1. Components and Timeline of the LINK-ET Training Program

Students participate in a research internship program (**A**) that offers training in cancer biology, proteomics, and health disparities. Each component is listed with important concepts or connections. Training was both didactic (**D**) and hands-on (**H**). The timeline of activities (**B**) is provided to illustrate the time spent in proteomics training and research internship as well as the points at which each evaluation was performed.

Table 1

Description of the Proteomics Training Curriculum

Lectures and labs were paired to prepare the students for carrying out experiments independently. Quizzes administered after Module 2 and Module 5 tested understanding using free response short essay questions. Lab reports for Module 2 and Modules 3–4 were designed to give experience in writing manuscripts for scientific journals. In Module 6, Protein quantification techniques have been used by each student in their research internship, so the quiz and lab report were not administered.

Curriculum Components
Module 1: Introduction
Concepts: Foundations of Proteomics
Lab Exercise: Tour of Proteomics Core and Labs
Skills: Understand Background
Module 2: Accurate Mass Measurement and Peptide Mass Fingerprinting
Concepts: Theory of MALDI-TOF-MS, Proteolytic Digestion, Protein Identification using Peptide Masses
Lab Exercises: Identification of Standard Proteins, Saliva Profiling
Skills: MALDI Instrument Operation, Protein Denaturation, Tryptic Digestion, Peptide Extraction, Database Searching
Module 3: Protein Identification using Liquid Chromatography-Tandem Mass Spectrometry Peptide Sequencing
Concepts: Affinity Purification, Liquid Chromatography, Tandem Mass Spectrometry, In-Gel Digestion, Peptide Sequencing, Database Searching
Lab Exercise: Analysis of a Protein Complex
Skills: MALDI MS/MS Instrument Operation, LC-MS/MS Sample Submission, Immunoprecipitation, SDS-PAGE, In-gel Digestion, Database Searching with Tandem Mass Spectra
Module 4: Proteome Cataloging
Concepts: Extension of Protein Identification, Proteome Fractionation by Gel-Based or Chromatography-Based Methods, Application to Biomarker Discovery
Lab Exercise: GeLC-MS/MS and MuDPIT *E. coli* Proteome Catalogs
Skills: LC Operation, Fraction Collection, Comparison of Analytical Methods, Quantification of Proteins by Spectral Counting, Summarization of Complex Proteomics Data
Module 5: Post-Translational Modification Analysis
Concepts: Molecular Changes by Modification, Separation Techniques for Enrichment, Phosphoproteomic Profiling, Utility in Assessing Drug Response
Lab Exercise: Analysis of STAT Phosphorylation in K562 Cells
Skills: Selection of Proteolytic Enzymes Based on Protein Sequence, Affinity Purification of Modified Proteins, Manual Verification of Modification Sites
Module 6: Protein Quantification
Concepts: Label-Free Quantification, Relative Quantification using Chemical Labeling (iTRAQ) or Biological Labeling (SILAC), Multiple Reaction Monitoring, Stable Isotope-Labeled Standard Peptides, Biomarker Evaluation
Lab Exercise: Develop Assays to Quantify Cancer-Related Proteins
Skills: Assay Development for LC-MRM, Data Analysis

Table 2
Students' Evaluation of Training Curriculum

The students were surveyed to evaluate their experiences in the training component of the LINK-ET program using Likert Scale scoring.

Assessment Elements	Likert Scale Score (Mean, n = 4)
Lectures (1, Needs Improvement to 5, Exceeds Expectations)	
Slides	4.25
Publications/Manuscripts	4
Handouts	4.5
Location	4.5
Interaction with Instructor(s)	5
Overall	4.5
Students' Understanding of Concepts (1 Completely Lost to 5 Easily Understood)	
Introduction	4
Accurate Mass Measurement & Peptide Mass Fingerprinting	4.25
Protein Identification & LC-MS/MS	4.25
Separations & Proteome Cataloging	3.75
Post-Translational Modifications	3.75
Quantification	3.25
Laboratory Exercises (1, Needs Improvement to 5, Exceeds Expectations)	
Environment	4
Instructional Handouts	4.25
Equipment	4.5
Access to Equipment	4
Time Allotted	4
Interaction with Instructor(s)	4
Overall	4.5
Students' Confidence with Experiments (1, Completely Lost to 5, Very Confident)	
MALDI MS	4
Peptide Mass Fingerprinting	4
Protein Identification & LC-MS/MS	4.25
Separations & Proteome Cataloging	3
Analysis of Post-Translational Modifications	3.25
Quantification	3
Data Analysis	3.75
Improvement of Analytical Skills	4
Increasing Students' Interests & Motivation (1, Strongly Disagree to 5, Strongly Agree)	

Assessment Elements	Likert Scale Score (Mean, n = 4)
Proteomics	3.75
Emerging Technologies	4.5
Cancer Research	4.25
Career in Research	4.5