

Strengthening Research Experiences for Undergraduate STEM Students: The Co-Curricular Model of the Research Experience

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Strengthening Research Experiences for Undergraduate STEM Students: The Co-Curricular Model of the Research Experience

Linda Blockus

Originally, participating in hands-on research under the guidance of a research scientist was an experience for the “chosen few” undergraduates who were hand-picked by faculty or were savvy enough to find their own opportunities. There are many stories of unsuspecting students who stumbled into research and found that the experience transformed their educational and career trajectories. In the last two decades, undergraduate research has become an expected educational activity for students seeking advanced STEM degrees. The educational and retention benefits of engagement in research are widely accepted, such that undergraduate research experiences are often implemented by institutions as an intervention to increase academic excellence, deepen scientific understanding and literacy, reduce attrition in STEM majors, and promote a diverse STEM workforce. The common acceptance that hands-on discovery research is a key learning experience for STEM majors has fueled the interest to increase opportunities, which in turn has fueled interest in course based undergraduate research experiences (CUREs) to increase capacity. However, the co-curricular/apprentice model will continue be seen as a necessary element of education for serious undergraduate STEM majors.

The purposes of this manuscript are to provide a discussion of defining co-curricular research opportunities, review structural features and variations, and propose a program framework to maximize best practices. Additionally, samplings of opportunities, consortia, funding sources, and federal programs that support undergraduate research are presented. The manuscript ends with a summary of challenges and recommendations to improve the practice and delivery of co-curricular undergraduate research experiences.

I. Defining the apprentice/co-curricular research experience

The Council on Undergraduate Research defines undergraduate research as an inquiry or investigation conducted by an undergraduate student that makes an original intellectual or creative contribution to the discipline. This definition does not provide context for when and where this activity should take place and can be used for both course-based experiences and individual experiences. A major challenge to the higher education community is that the common concept of the phrase undergraduate research is a conglomeration of behavioral attributes and assumptions. There is no standard convention for an operational definition that includes logistical and quantifiable activities to specifically define undergraduate research.

A number of sources point to some general behavioral expectations of what the student will learn and accomplish. These activities include reading primary literature, designing a project, ownership of the project (including the opportunity to problem-solve), learning scientific techniques, analyzing data, communicating results, and interacting with a research mentor regularly (Lopatto, 2009; Della-Piana, Kubo Della-Piana, & Gardner, 2014). A student-centered developmental continuum of research understanding and mastery is used as a rubric by some institutions to assist faculty in recognizing the activities students should be undertaking as part of the research experience. For example, George Mason University’s Students as Scholars

initiative uses a rubric for both class experiences (CURE's) and "individualized scholarly activities" such as mentored lab research projects (see, Students as Scholars master rubric from George Mason University, <http://assessment.gmu.edu/wp-content/uploads/2013/08/Students-as-Scholars-Master-Rubric-Updated-July-2013.pdf>). The University of Kansas uses a skill progression of exposure, experience, and expertise (J. Augusto, personal communication). Willison and O'Regan (2008) developed a Research Skill Development Framework that demonstrates the progression of student autonomy in their activities and which includes initiating a research question, collecting and evaluating data, and presenting the new knowledge to a variety of audiences. A recent article by Shanahan, Ackley-Holbrook, Hall, Stewart, and Walkington (2015), lists ten salient practices of student research mentors. According to their review of the literature, mentors should be teaching skills to conduct research appropriate to the discipline, increasing the student's ownership of the research over time, and encouraging students to present their research findings.

A common pathway to research is for students to begin working on a part-time basis in a faculty research lab or team and taking a semester or more to "learn the ropes" before taking ownership of advanced responsibilities. Faculty may pair inexperienced students with an intermediary supervisor, such as a graduate student or lab technician, for day-to-day training. Students are often assigned to be the assistant to a more experienced member of the lab and receive one-on-one training through observation and support in on-going experiments and projects. Because of the specialized equipment and supplies required for many scientific disciplines, this training needs to take place physically in the lab, field, or at computers with specialized software, and generally cannot be self-taught through books or online learning. This initial on-the-job training to develop competence over a period of time can occur in the context of an hourly job or volunteering between class times. Although some students develop their research skills and independence over an extended period of time, other students (visiting summer interns, for example) may enter a research environment with previous experience and have a shorter and steeper learning curve; although they will still learn-by-doing under the guidance of a more experienced researcher. This approach to situational and observational learning in the context of undergraduate research is sometimes labeled as an "apprentice model."

In his early work identifying key features of undergraduate research, Lopatto (2009) categorized three types of experiences: the employee (doing support work but having no intellectual input into the research), the apprentice (participating fully in the research process in a team setting; earning academic credit or a stipend; collecting, analyzing and presenting data), and the fellow. A research fellow was described as having the same expectations and output as an apprentice (presentation/paper based on research findings), but was more likely to work alone, checking with the faculty mentor only as needed. With Lopatto's classifications, the fellow description seems to be more a function of the nature of research in the discipline (mathematics, humanities), than the level of student independence. For some institutions and programs, the title of apprentice or trainee may connote a subordinate status to other titles that may imply a more prestigious status or increased funding such as scholar, fellow, or intern. Although there is no common agreement on a particular title for the student, it is commonly accepted that the traditional approach to participating in lab-based research is to conduct it between or after classes, as an addition to formal lecture and lab classes. The need to conduct research in specific physical space between classes is in contrast to other how other disciplines may conduct

scholarly work. For example, art student projects may originate from course assignments and be done during studio class time. Humanities students can proceed with their work at home in the evenings without specialized equipment or assistance with complex protocols. STEM students may be earning academic credit for their research work; however, a formal meeting time, classroom, syllabus, and classmates are not required. The phrase ‘independent research’ draws some criticism from faculty who point out that the experience is not truly independent of guidance or team support in the STEM fields. Perhaps using the phrase ‘co-curricular research experience’ is a better description of the activity that occurs outside a formal classroom and may imply greater potential for intellectual engagement than the title of ‘research.’

II. Models of the practice of co-curricular research for undergraduates

A review the basic operational and logistical variations used to facilitate and structure undergraduate research demonstrates the diversity of methods practiced. Following a short overview of time, academic credit, financial compensation, and typical program elements, a brief section on infrastructure considerations is provided. Examples of structural variations and enhancements to the preparation for and practice of undergraduate research can be found in the subsequent section.

Time: Among academic year programs, generally 10-15 hour per week is the standard expectation for the student doing co-curricular research. The practice of full-time immersive summer programs is pervasive, although the number of weeks varies by institution and practical limitations. Faculty researchers seem to follow the ‘more is better’ approach and prefer 12 weeks if they can get it. Very few programs are less than 8 weeks. The National Science Foundation Research Experiences for Undergraduates (REU) program solicitation does not dictate the length of a summer program; however, the programs seem to average 10 weeks. NASA is working to standardize their summer program to 10 weeks. The length of a summer program may depend on external factors such as when student housing is available and an institution’s academic calendar. Summer programs that are longer than 10-12 weeks may risk discouraging student applicants who are also trying to squeeze in other summer activities. Aligning program dates of schools and students on a semester system versus a quarter system can be a challenge too. Short of a universal college calendar, there will always be variations in the length and timing of summer programs. Some programs are purposefully designed to begin with a full-time experience in the summer to jump-start the student’s project, followed by an academic year, part-time experience to complete, write and disseminate the research. The University of Delaware offers a non-typical summer option for students already involved in research or planning to continue during the academic year. Delaware undergraduates can apply for the traditional full-time Summer Scholars program and earn \$3500 for 10-weeks. However, if undergraduate researchers are taking a summer school class, engaged in volunteer activities, or have other summer obligations, they can apply for the Summer Fellows program and receive \$300-\$1500 for a reduced work effort. Two-hundred Scholars are supported each summer and another 50-60 students receive part-time Fellow support (www.urel.udel.edu/urp/summer-research/ and L. Barsky, personal communication).

Conducting undergraduate research is not limited to the junior or senior year or to just one summer. There is a growing trend to make co-curricular research opportunities available to

underclass students, in addition to traditional opportunities for juniors and seniors. First- and second-year students engaged in undergraduate research can continue their research involvement at their own institution as upper class students or participate in one, or more, off-campus summer programs. Students may be advised to spend their first full-time summer at their home institution before applying to off-campus programs the next summer. Undergraduates participating in the NIGMS-funded training programs are strongly encouraged to have at least one summer at a research-intensive institution. Two summer experiences at different institutions can be an opportunity to compare potential graduate programs in different parts of the country. Two consecutive summers with the same faculty mentor, however, may result in greater research productivity for the student. The HHMI EXROP program now offers a second year to eligible students for this reason. With the variety of options and sequences available to students, coupled with the competition for summer program positions, students can benefit from the advice of faculty mentors and undergraduate research program directors.

Academic Credit: There is enormous disparity on institutional policies regarding the amount of academic credit students may earn through participation in research. Variation includes the number of credit hours major requirements, credit hours towards degree requirements, and earning credit while also receiving financial compensation for research. Some institutions (Maryland, Florida Atlantic) do not allow students to gain financially for conducting research while they are also earning academic credit. They may offer an either/or option for students -- either earn money or earn academic credit. Austin College students earn credit during the academic year and then are put on payroll in the summer. At North Carolina State University the policy depends on the academic department. Other institutions do not have rules against earning credit and money at the same time (Missouri, Arizona). Depending on the tuition structure of an institution (flat-rate for full time or cost per credit hour), students who wish to earn academic credit may need to pay additional tuition to have it documented on their transcript. For example, biology majors at the University of Missouri can only use up to six research credit hours towards their degree; therefore there is usually no benefit to the student for paying for extra hours after paying for the first six credit hours. Some institutions (Georgia, Florida, Texas A&M) offer a zero-credit option so that continued research efforts can appear on a transcript. Summer programs may require visiting research interns to register for credit so that they have official status as a student and therefore access to libraries, computing services, and student health centers.

Departments and institutions have their own standards and methods for assigning grades for academic credit. Assigning letter grades (or pass/fail) is typically the sole responsibility of the faculty research mentor. There may be specific rules about what types of experiences are worthy of academic credit. Depending on the program or nature of academic credit, students may be expected to report to a third party by preparing a project proposal, submitting progress reports, meeting individually with a course director/honors director, or completing a final manuscript or reflection essay. George Mason University provides mentors with their 'rubric', requesting that faculty report back on the experiences and level of learning students are reaching. Although the office does not use this information to assign grades to students, the office receives an overview of students' involvement and learning which can be used by the university to monitor the experiences and levels of engagement.

The program's ability to pay for academic credits or waive tuition and fees depend upon the regulations of the funding agency and the fiscal culture of the institution. In some cases, students may receive a scholarship that intends to cover the extra cost of academic credit for research. Student researchers at non-university facilities, such as biotech firms or museums, may not have to worry about registering for academic credit but may need to be compensated to obtain appropriate employee status or special appointments that grant appropriate access to facilities and services.

Financial compensation methods: Student compensation is very complex. Students who are beginning their research experience and taking on support tasks (washing dishes, entering data) may volunteer to help faculty and graduate students. Students who have federal work-study eligibility may use these funds to secure a job with a faculty member – at some institutions, work-study funds are purposefully used to support undergraduate research opportunities. Students may also be paid an hourly wage from faculty grants or university funds through the campus payroll system. The campus may have a standard hourly rate higher than the state minimum wage. When a student advances to the level of conducting an independent project, compensation may be more complicated if there are particular guidelines from the funding agencies or institution. Programs or institutions may not allow students to be paid an hourly wage as 'salary' because the expectation is that undergraduate research an 'educational experience' for the student (benefiting the student) and not a 'fee for services rendered' (benefiting the employer). Some upper class programs or institutions require that students be compensated through payroll (Arizona, Wisconsin-Eau Claire). If not disbursed through payroll, money may need to be given to students in the form of a scholarship and be processed through the institution's financial aid office (Missouri, Stetson). Depending on the student's level of financial need, awarding a \$3000 scholarship stipend may immediately reduce the loan or grant provided by the institution for the student. For some students, it is more financially expedient to work at a fast-food chain and maintain their campus financial aid, rather than risk reducing their financial aid package with a scholarship stipend to do research. There may also be a need to do an end-run-around of policies to provide students a financially feasible way to cover living expenses for a summer program. One such method when direct payment is not permitted is to increase the stipend amount and then ask the students to pay for their room and board from their stipend. Faculty members who fund students from their grants may not always be aware of the different and subtle intricacies of funding agencies, institutional human resources, and institutional financial policies of paying students. It may get even more complex when a student is not an enrolled in the mentor's institution or graduates a semester early and does not retain student status. Tax implications and health care coverage are also confusing to students and their parents. Given the various policies of agencies and institutions, there may never be a common agreement on when and how students should be compensated for the time put into research endeavors; however, it would be a benefit to all if the options were not as confusing and dependent on local interpretation. Some may argue that an educational experience is the ultimate benefit; however, lack of financial compensation is not a feasible option for most college students today.

Student Research Findings and Communication: An important part of student research is the opportunity for the student to summarize and share their project findings. It is important to share knowledge to advance science and important for the student to communicate research findings

for their educational development. In scientific research, publishing a peer-reviewed journal article or presenting research at a national conference are expected accomplishments. Some undergraduate students achieve this level of success. However, for many students this level of accomplishment is not expected; therefore, programs will organize experiences appropriate for undergraduates. Because undergraduate research can be framed as a student-centered activity, all presentation opportunities are very valuable for the students, even if they are not done at a national conference. Poster sessions and oral presentations are common on college and university campuses and may be conducted in the context of events that celebrate undergraduate scholarly and research projects from all disciplines or more focused events such as senior honors presentations in the chemistry department or a research day for undergraduate and graduate students for a college of engineering. Students may also complete a research paper or more formal written senior thesis. Attending regional or national conferences is recognized as a mark of accomplishment and an educational experience. Some programs purposefully plan for their students to attend and present at disciplinary meetings or attend a more student-focused conference such as the Annual Biomedical Conference for Research Students or regional Psi Chi conferences for psychology students.

Formalized structure: The level of formal structure of the educational practice of undergraduate research can run the spectrum from an experience casually orchestrated by the faculty mentor to a highly organized outline of expectations monitored by a third party. Without explicit guidelines from the institution, the experiences of students will largely depend upon the faculty mentors' level of involvement and philosophy on why they work with undergraduates. Although faculty may provide purposeful instruction and hold undergraduates accountable for milestones such as reading primary literature, designing their own experiments, presenting data to the research team, writing abstracts and papers, and presenting projects at a public venue, mentors may also take a hands-off approach without ensuring key learning opportunities or providing educational feedback to students. Programs that require students to submit abstracts or papers, make public presentations, and ask students to put their project into a societal context will at least ensure that students are doing more than generating data for use by the research team. Institutions that have formalized senior honors thesis programs may require weekly group seminars over the period of one or two semesters. At the University of Central Florida, the Honors in the Major program is highly formalized (<http://research.honors.ucf.edu/honors-in-the-major>). Students register for a six-credit sequence; must submit an application, proposal, and final thesis; identify a committee and faculty chair; and participate in an oral defense. Students also attend a mandatory orientation and workshops. At the University of Missouri, we were interested in encouraging specific student-mentor interactions in our summer, although we had no formal mechanism to enforce meetings with independently funded student-mentor pairs. With student survey data collected and then shared with mentors during summer orientation in 2011, mentors learned that 69% of students attended lab meetings, 67% practiced their posters with members of their labs prior to the poster session, and only 37% of students had a debriefing meeting to discuss the experience of presenting their posters. By 2014 those percentages increased to 80%, 81%, and 58% respectively. Even with a less prescriptive and deadline oriented program, a bit of infrastructure can collect valuable data, promote expectations, and influence behavior (Cohen & Blockus, 2015).

Workshops/Professional Development: A standard part of undergraduate research programs for cohorts of students is a series of workshops and seminars on topics related to communication of research and professional development for advanced education and STEM careers. The frequency and depth of the workshops and seminars will depend on the local culture and the director's opinions on the level of professional development to provide in a group setting. For example, there may be a weekly Responsible Conduct of Research (RCR) discussion throughout the summer or just one sixty-minute session. The nature of the activities will also depend on the target audience. Programs that aim to increase graduate school applications/admissions are likely to cover the admissions process, interviews, fellowships, and GRE prep. Other topics include writing abstracts, tips on making presentations, science career options, and selecting graduate school mentors. Summer programs may include a series of "journal club" sessions, scientific seminars, or science-related field trips. The effective program director will strive to find the right balance between research time and time for 'extra activities' that pull students away from their projects. The balance will depend on the goals of the program, target student population, and expectations of faculty mentors. Too much time away from the 'research bench' slows the research process and student learning. However, the research experience is also developmental in nature at a time when students are working on issues beyond developing research skills. The impact of the 'extra activities' and the value of a peer community can sometimes be overlooked by research mentors.

Infrastructure: A detailed description on the different approaches campuses use to coordinate undergraduate research experiences and needed infrastructure can be found in *Undergraduate Research Offices & Programs: Models & Practices* (Kinkead & Blockus, 2012). Undergraduate research offices provide "how to" advice about getting started on their website, in handouts, at workshops, or even videos (see Michigan State University: urca.msu.edu/video and Northwestern University's YouTube channel: undergradresearch.northwestern.edu/). Getting involved or getting into a lab is just one step of the process for students, that may come before or after or during a formalized 'Research 101' type of course that has been developed and offered at a number of institutions. The University of North Carolina Wilmington offers a spring seminars for students in different disciplines (ie, sciences, education, social sciences) that includes literature searches and data collection practices appropriate to the discipline (uncw.edu/csurf/hon292.html). The University of Connecticut biology department offers a one-credit seminar for a parade of faculty to talk about their on-going research (web.uconn.edu/mcb/undergraduate/research.html). At North Carolina State University, the life sciences unit has an optional two-semester, six-credit hour course sequence to prepare students to conduct original research. The program is nicknamed the "Research PackTrack" as a nod to their wolfpack athletic mascot. There is an affiliated student organization (PackTrack Club) to facilitate continued involvement, support, and outreach (researchpacktrack.wordpress.ncsu.edu). Undergraduate research offices can be valuable partners with science departments to broaden outreach to diverse student populations and provide suggestions for introductory experiences for students. Typically centralized offices will offer student travel awards, coordinate undergraduate research symposia/celebration days, and may sponsor a campus journal for student publications.

Externally funded research programs may not always be found in a centralized undergraduate office. For example, an REU site program may be housed in the physics department, undergraduate research office, graduate school, or interdepartmental research center. A number

of campuses and undergraduate research program directors recognized the opportunity for the logistical and programming economies of scale that can be realized through multi-program collaboration. The Ohio State University has offered the Summer Undergraduate Research Institute (SURI) for the past seven years as a mechanism to bring together student researchers for educational and social activities. In 2014, 511 students were listed as SURI participants. Seventy-six percent of these students were members of 25 different formal programs. The other 123 students were conducting research independently with faculty and not in an official program. Eighty-seven percent of the students were in the STEM disciplines. In addition to offering educational programs to compliment their experiences, SURI provides a sense of community and a supportive network valued by the undergraduate participants. Additional information on SURI programming and evaluation can be found in the *Undergraduate Research Office 2014 Annual Report* (undergraduateresearch.osu.edu/about/2014_URO_Annual_Report.pdf). The summer program coordinated at the University of Missouri (MU) is smaller in size (~100 students); however, provides logistical support beyond organized educational and social programming. The Undergraduate Research Office at MU will coordinate visiting student applications, enrollment and fiscal paperwork, travel and housing logistics, and trouble shoot the variety of bureaucratic challenges that arise with health fees, stipend payments, meal plans, etc. About 50% of the students are visiting students supported by three REU site programs, university funds, and faculty grants. For a service fee, the office staff manages logistical arrangements for groups of students or an individual student supported by a faculty grant. Students are incorporated into the larger program from the start, including roommate assignments and orientation sessions. Developing a community of peers from a variety of institutions and scientific disciplines is a motivating factor for this approach. It also creates a critical mass of diverse students. Collaboration between programs can benefit the students, faculty mentors, and institution and reduce expenses and redundancy.

III. Structural variations and enhancements

First year programs – One of the best known undergraduate research programs for first year students is the UROP Program at the University of Michigan (lsa.umich.edu/urop). Other programs, such as the Research Rookies at Northern Illinois (www.niu.edu/researchrookies/) are adaptations of the UROP early entry model. More recently, the First-Year Innovation & Research Experience (FIRE) program at the University of Maryland has offered an elaborate, three semester program that purposefully involves PhD-level “research educators” to provide leadership and support to the team of ~30 students, 4 peer mentors, and one or more lead faculty researchers. Currently there are 12 different “streams” (a team working on a cluster of research topics) that involve more than 400 students. Students earn credit, complete a prescribed curriculum, and engage in team-based research and innovation projects. (fire.umd.edu/) The FIRE program at Maryland is based on the 10-year old Freshman Research Initiative (FRI) at the University of Texas (cns.utexas.edu/fri). This multi-semester, team research concept seems to be a hybrid of course-embedded research and co-curricular research. A FRI Conference is being held in early March 2016 to discuss best practices and adaptations of the FRI model (cns.utexas.edu/fri-annual-conference).

Multiple year/multiple level programs – Although the Michigan UROP and the FRI models serve as launching pads for students to enter individualized scholarly activities other programs have

been designed as multi-year experiences. The best known model is the Meyerhoff Scholars program at UMBC (meyerhoff.umbc.edu). In addition to research opportunities and linkages with related programs and partners (HHMI, Leadership Alliance, LS AMP, NIGMS-MARC), Meyerhoff students are part of a supportive community during their undergraduate years and beyond. Academic advising, financial support, a summer bridge program, study groups/tutoring, and undergraduate research are interwoven into a mutually reinforcing experience for the students. Another example of a multi-year program is the EXPRESS program at the University of Missouri which is supported by a IMSD grant from NIGMS and housed in the Office of Undergraduate Research (undergradresearch.missouri.edu/programs-jobs/programs/express.php). After a semester of attending weekly workshops and meeting with peer mentors, EXPRESS Apprentices can begin working in faculty mentor laboratories and earn an hourly salary while continuing to attend group and peer mentor meetings. Upperclass students can transition to the EXPRESS Fellows program to conduct their own research project, participate in intensive summer research programs, and prepare applications for graduate school. The peer mentoring component of the program is a unique feature, as carefully trained upperclass students provide advice on interviewing faculty for research jobs and succeeding in a research setting in addition to academic and social transitions. The community of ~100 apprentices, fellows, and peer mentors (all underrepresented minority STEM students) helps to promote an academic/research identity, as well as support the cultural/ethnic identity of its members. Weekly Fellows meetings focus on professional development, research presentations, preparing for graduate study, and continuation of the supportive community.

Students in UMBC's Meyerhoff program or MU's IMSD EXPRESS program benefit from the support of a multi-year peer community in addition to their research experience. Their undergraduate research involvement is experienced as an individual in a traditional co-curricular approach at their home institutions during the academic year and then in full-time summer research programs. These programs are not specifically designed for a 'team research' experience. A different model of multi-year engagement is the Vertically Integrated Projects (VIP) Program (www.vip.gatech.edu). The VIP program provides a multi-semester experience for students, allowing them to join an on-going research team and advance in their leadership roles and research contributions. Undergraduates earn academic credit each semester, graduate students gain mentoring skills, and faculty researchers benefit from a sustainable team of engaged students working on a long-term research project. Teams are typically 10-20 undergraduates and a handful of graduate students. There are currently 17 colleges and universities in the United States that have or are adopting the VIP model (www.vip.gatech.edu/vip-consortium). A consortium planning meeting was held in 2014 and the consortium was launched in 2015, led by Georgia Tech and funded by the Helmsley Charitable Trust. The VIP approach "fosters innovation by involving students in challenging projects embedded in faculty research." Although the approach is not limited to engineering students, this model was designed to meet the needs of engineering researchers and students in academia. Even though VIP students earn academic credit and have a set group meeting time, it is self-paced experience without the formal structure of a course and therefore could still be considered a co-curricular experience and not be classified as a CURE model.

Adaptations for non-research institutions – Institutions that do not have a research mission or research-active faculty need to consider other models. Examples from community colleges can

be found in a number of CUR publications (Brown, Higgins, & Coggins, 2007; CUR/CCURI, 2015; Guertin & Cervený, 2012; Hensel & Cejda, 2014). The Undergraduate Research Opportunities Center (UROC) at California State University at Monterey Bay expands their capacity to provide opportunities for their students by preparing them for and facilitating placement in off-campus experiences (csumb.edu/uroc). Their staff provides a sequence of preparatory and follow-up courses for professional development and to maximize the research experience. Individual coaching, peer-peer support, and courses and workshops work together to empower students to develop self-efficacy and identity as research scholars. Students can apply for funding through the CSU LS AMP program or the campus McNair Scholars Program, or apply for traditional summer programs at other institutions. For more information on the UROC approach, see Brown and Head (2012) and O'Donnell, Bothello, Brown, Gonzalez, and Head (2015).

Living/Learning Residence Hall with a focus on undergraduate research – The Michigan Research Community (MRC) was developed more than fifteen years ago as an add-on residential option for freshmen participating in the University of Michigan's UROP for underclassmen. Current residents include 113 first year students and 35 returning students. The community is not limited to STEM majors; however, 40% of the residents are in engineering and more than 50% of residents are enrolled in the College of Literature, Science and the Arts. The MRC holds their own research symposium in addition to the larger UROP symposium (www.lsa.umich.edu/mrc). Based on the success at Michigan, the L.E.A.R.N. (Learning Environment and Academic Research Network) at the University of Central Florida was established in 2011 with funding from NSF. L.E.A.R.N. participants receive a scholarship, enroll in a two-semester 'introduction to research' course, and participate in a 12-week research apprentice experience. The program is limited to under 30 first year students; however, is open to all STEM disciplines. The program seeks to build pathways for students to apply for UCF upper class research programs such as McNair or LS AMP (www.our.ucf.edu/learn/freshman.php). The programs at both Michigan and UCF were developed by leadership from their undergraduate research offices. The concept of a residential community for undergraduate researchers is currently being adopted at Florida Atlantic University and Western Carolina University. More detailed information can be found in Schneider and Bickel (2015) and Schneider, Bickel and Morrison-Shelton (2015).

Short-term training prior to a summer research experience – Multi-day "boot camps" can provide novice students with some basic technical skills, science research skills, and a research socialization experience in a 'safe' peer environment before beginning an intense-full time research experience. These types of enhancements may be particularly impactful to first-time researchers or visiting students who may benefit from a boost of research or social confidence. Programs may emphasize technical skills over professional development topics. These training sessions may also be used for RCR education early in the summer. One example of such a program is the five-day "Lab Fundamentals Bootcamp" offered by the Quantitative Biosciences program at UC Berkeley (QB3-Berkeley). The goal is to provide a "molecular biology experimental primer" for students participating in QB3-Berkeley biotech industry summer program and includes training in basic technical skills, experimental designs, and use of standard software (qb3.berkeley.edu/qb3/bootcamp.cfm). Another example is the Undergraduate Molecular Biology Lab Skills Bootcamp at Virginia Commonwealth University (VCU),

sponsored by NIGMS diversity training programs (IMSD, MARC, Bridges) at VCU. This program is a five-day opportunity in May for VCU students to gain hands on molecular biology skills before beginning their own research experience at VCU or elsewhere (<http://www.research.vcu.edu/ugresources/bootcamp.htm>).

IV. Institutions and organizations providing opportunities

No comprehensive study has been undertaken to catalog all of the locations and funding sources for undergraduate research opportunities in the STEM disciplines. Most four year institutions where science faculty are expected to conduct research as standard part of their job duties have at least some opportunities for undergraduates. Faculty job announcements at PUIs routinely call for experience in engaging students in research as part of the job qualifications. However, colleges and universities that offer undergraduate STEM degrees are not the only hosts for undergraduate research. Medical schools and biomedical research centers that do not offer bachelor's level STEM degrees are another source of funded opportunities. A listing of training and degree programs on the Association of American Medical Colleges GREAT Group (www.aamc.org/members/great/resources/) includes programs at seventy-plus medical schools, including the Mayo Clinic, Mount Sinai School of Medicine, and the Medical University of South Carolina. A separate link on this website lists thirty-five medical schools that offer summer research programs specifically for undergraduates wanting to explore the MD/PhD option. Medical research centers, such as Fred Hutchinson Cancer Research Center and St. Jude Children's Research Hospital also offer undergraduate research opportunities. Field and marine research stations, some of which are directed by a consortium of higher education institutions, offer summer programs. Shoals Marine Laboratory (NH), Hatfield Marine Science Center (OR), and the Whitney Laboratory for Marine Bioscience (FL) are examples of marine stations. Examples of ecological field stations with undergraduate research programs include the Rocky Mountain Biological Laboratory (CO), Kellogg Biological Station (MI), and Highlands Biological Station (NC). Many non-profit museums, zoos, aquariums, and botanical gardens that include research in their strategic missions provide research opportunities for undergraduates. Examples include the Mote Marine Laboratory & Aquarium (FL), the Missouri Botanical Garden, the Field Museum (IL), and the San Diego Zoo Institute for Conservation Research. Biotech, chemical, and engineering companies, such as Genetech, Monsanto, Pfizer, and Boeing, offer college internship programs, although the level of research engagement may vary. Non-profit and federal research facilities host undergraduate researchers and include the Howard Hughes Medical Institute Janelia Research Campus, Jackson Labs (ME), the Danforth Plant Sciences Center (MO), National Radio Astronomy Observatory, Los Alamos National Laboratory, Oak Ridge National Laboratory, and the National Institutes of Health. Detailed examples of programs at non-university sites can be found in Blockus & Wilson (2012). Recommendations for hosting summer interns for educational, non-profit, and industry sites can be found in section 10 of Characteristics of Excellence in Undergraduate Research (COEUR) (Hensel, 2012).

Although many universities, research facilities and companies coordinate formal summer research programs for undergraduates, students can also set up their own summer research experience informally through networking, personal connections, and internship postings. One of the challenges of describing the undergraduate research opportunity landscape is that students do

not have to be in a formal program to have a research experience. These ‘unregulated opportunities’ can have positive and negative aspects. Some students may have better luck finding a position through a network rather than competing against hundreds of peers for a slot in a formal summer program. Research mentors, especially at start-up research companies, may be working in organizations that are too small to coordinate a formal program. Students may be able to work out arrangements with their mentor for a part-time experience in the summer, higher pay, or days-off for other summer activities. The quality of the experience will always depend on the quality of the mentor and the effort of the student, whether in a formal program or not; however, there are no checks and balances with independently arranged experiences. Students may find themselves in uncomfortable or unproductive situations with no program director to provide mediation. Research mentors may not have guidelines or infrastructure support to reduce uncertainty and logistical burdens. Both students and research mentors need to be cognizant of potential pitfalls of independent arrangements.

With the diverse range of programs and institutions, it is an annual struggle for these programs to disseminate their information, for student advisors to share information with their students, and for students to learn about all of the opportunities. A recent (November 2015) on-line discussion from CUR undergraduate research program directors highlights the common problem and variety of solutions. The question was asked to colleagues on how they keep track of and share off-campus summer programs. Responses included adding individual program links to a campus office website, sending out emails to students with listings of program information that had arrived that week, putting information into an online ‘course folder’, and developing and maintaining their own database of opportunities. One institution staffer put together a handout/spreadsheet that listed more than 100 biomedical research programs at 87 different locations that included program dates, application deadlines, student benefits (stipend, lodging, travel), and the program URL. Countless numbers of hours are spent by staff at many universities who update their own database or add to a home-grown listing on the web, and the quality and breadth of these listings vary. There are a number of digital companies, often times started by undergraduates, attempting to collect, package and sell publically available information on student programs. One such organization is the Student Opportunity Center (www.studentopportunitycenter.com) which claims to have a database of more than 10,000 opportunities including student conferences, journals, and internship/scholarship/research programs. Institutional subscriptions can range from \$2000 - \$20,000 per year, depending on institutional size. Some disciplinary societies host their own website listing or database relevant to their discipline. NASA has their own database for NASA-funded opportunities (see Appendix 3). There has not been an effort to catalog and consolidate all of the different programs across STEM disciplines and students are best served by searching many different listings and databases. A sampling of the more extensive listings or listing of listings appears in Appendix A.

One approach to consolidate information, increase outreach and applications, and share best practices is the development of consortiums. Appendix B provides brief snap shots of several different types of consortia that may be organized by discipline (Keck, CURM), institutional type (CIC), targeted student audiences (Leadership Alliance, HHMI EXROP), or funding sources (HHMI EXROP, Amgen Scholars). In addition to an expanded recruitment base, some consortia leverage their collaboration with a common application for all member institutions. Other

consortia use their website to direct students to the member websites for application and program details. All but one of the example consortia utilize their own national student conferences to bring together undergraduates for professional development, career opportunities, networking, and research presentations. Some consortia organize opportunities for site directors and faculty mentors to discuss best practices and plan future initiatives. Most groups have a system to track student participants and/or evaluate programs. The alumni networks that develop are a direct result of aggressive student follow-up that may not be possible with larger programs or programs that do not have an institutional investment in consortium membership. Interestingly, some universities are members of multiple consortia. For example, the University of Chicago is a member of both the CIC and the Leadership Alliance. Stanford belongs to the Amgen Scholars program and the Leadership Alliance. Recruitment of highly qualified graduate students and research scientists is certainly one goal that members hope to leverage through their participation in consortia; however, no research has been done to determine if member institutions fare better than peer institutions that are not part of these organizations.

V. Funding of co-curricular research opportunities

As discussed previously, not all students receive financial compensation for their time spent on individualized scholarly activities. Some programs and institutions grant academic credit in lieu of money, and in many cases, students have to pay for the academic credit. Undergraduate research is viewed as an educational credential that needs to be paid for. Students may also participate in research on a volunteer basis, and receive neither credit nor pay. If a student has federal work-study eligibility, often times they can work with their institution to use that funding to support their time conducting research. Colleges and universities have elected to use general operating money, endowment funds and scholarships, and return on indirect grant funding to support students – funding sources depend on institutional culture and budgets. Faculty members with external grant funding may elect to set aside funds to support undergraduates. Faculty seeking NSF support to fund their research may leverage undergraduate research experiences as a way to fulfill their broader impacts requirement (see Blockus & Renoe, 2016).

Many federal agencies sponsor programs that are specifically designed to increase the number and diversity of undergraduates engaged in research and/or promote academic success in the STEM fields (for additional details, see Chapters 11 and 12 in Kinkead & Blockus, 2012). A brief overview of some of the programs sponsored by the USDA, Department of Education, NSF, NIH, and NASA can be found in this manuscript in Appendix C. Programs may also be available through NOAA, Department of Energy, and the Department of Defense. Students may also secure funding through professional organizations and societies. The American Society of Plant Biologists provides a \$4000 stipend and funding to attend the Plant Biology annual meeting (surf.aspb.org). The American Heart Association offers a limited number of summer fellowship awards of \$5000 (http://www.heart.org/HEARTORG/Affiliate/Founders-Affiliate-Local-Research-Opportunities_UCM_315885_Article.jsp#.VtXWBSlnhOV). In addition to providing student support (through a salary or scholarship), funding is also needed to cover consumable supplies and equipment time, printing posters, and attending conferences. Summer programs for visiting students will also need to consider expenses associated with room and board, travel, tuition and application fees, and health center fees. Depending on the culture of the institution or organization, earmarked funding may also be needed to cover program

expenses, program staff salaries and supplies, and mentor support. Depending on the policies of external funding sources, faculty and staff salaries, tuition, or indirect/administrative allowance may not be permitted and therefore institutions may need to reallocate institutional funds. Additional discussion on expenses associated with co-curricular undergraduate research can be found in the COEUR document (2012) and Kinkead & Blockus (2012).

VI. A program model for quality engagement

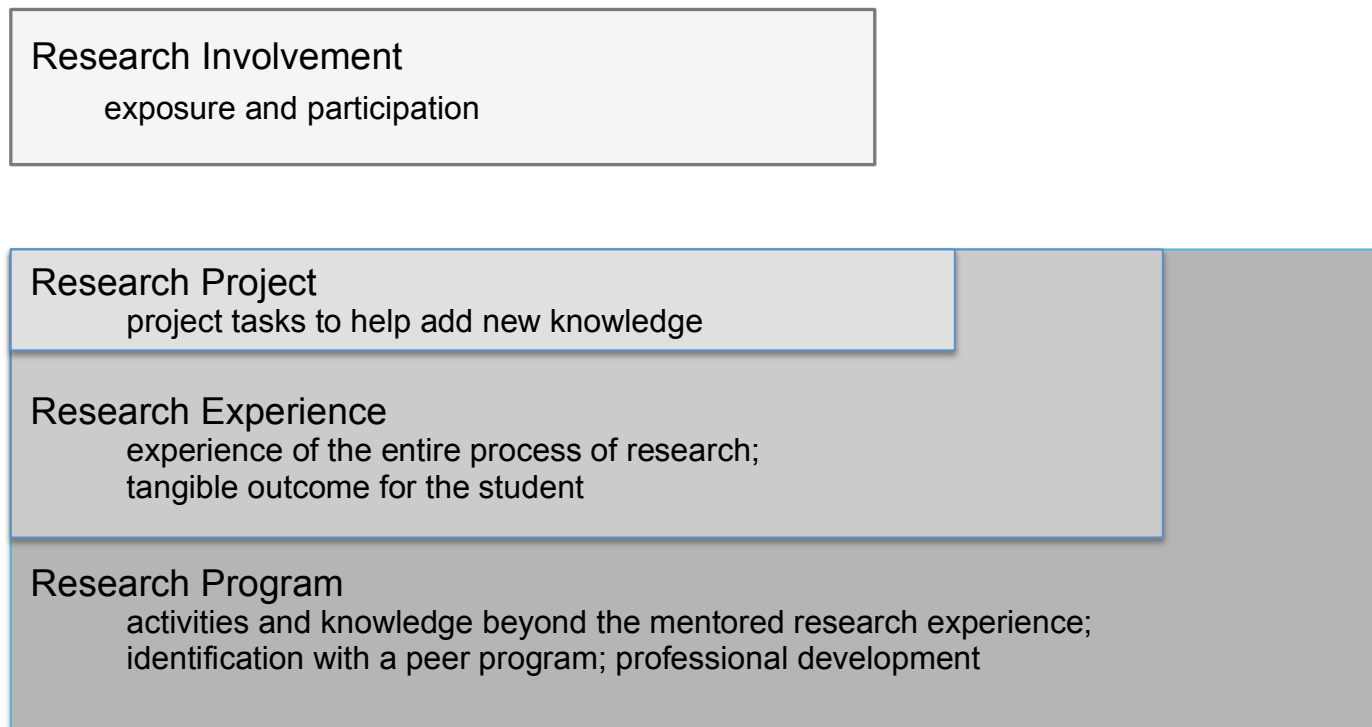
Undergraduate research is considered to be one of ten high-impact educational practices (HIEP) that promote college student success and have positive benefits on student learning and personal development (Kuh, 2008). Other high impact educational practices include first-year seminars, service learning, writing-intensive courses, and learning communities. Qualities that define HIEP include interaction with faculty and peers over an extended period of time, frequent feedback on student performance, and opportunities for students to see how their growing knowledge can be applied beyond college. Additionally, HIEP should provide opportunities for students to experience diversity and gain in self-awareness. To benefit from engaging in HIEP, students need to invest a considerable amount of time and effort. Understanding what makes for an effective HIEP experience can be helpful to create an undergraduate research environment of high expectations and best practices.

The terms *undergraduate research*, *undergraduate research experience* (URE), and *undergraduate research program* are often and casually used interchangeably to describe the learning activity of student engagement in discovery research. There are, perhaps, subtle and important differences between such terms that vary in regards to the core student activities/learning, professional development delivery, infrastructure, products, and the learning environment. A student who is conducting undergraduate research isn't necessarily in a program. Colleges and universities where students have opportunities to conduct research can not necessarily claim to have an undergraduate research *program* at their institution. Some institutions with formalized programs have been quick to claim that they have *excellent programs* in recruitment materials and campus tours without stopping to define and measure what excellence is.

One of the major catalyzing factors for developing the *Characteristics of Excellence in Undergraduate Research* (COEUR) document was to create a guide describing quality institutional environments for dissemination to the higher education community – or in other words, what can be used to gauge the level of excellence? COEUR addresses many institutional infrastructure issues related to supporting a quality environment for faculty mentors and departments. In sections 8 and 10, COEUR begins to explore elements that relate to the student experience; however, COEUR does not organize the elements in a holistic, student-focused model to define levels of student experience. Brownell and Swaner suggest that future research on high impact educational practice needs to begin with clear definitions of the practices. “Popular definitions of many high-impact practices are very broad, making it difficult to determine what specific factors within each practice are crucial for positive outcomes” (Brownell & Swaner, 2009). In addition to clarifying definitions, a deeper understanding of how the activities are implemented and experienced by the student are needed to ensure quality. “To engage students at high levels, these practices must be done well” (Kuh, 2008, p. 30).

Educational practices should be “done well” to maximize the transformative nature of the activity and realize a positive return on the investment of time and resources. Other rubrics and frameworks of undergraduate research have provided insights on how the student develops as a researcher, but fail to account for the influences of formal structures, educational programming, and peer-peer interactions. To envision a holistic developmental experience for the undergraduate to aim for maximum impact, a new student-centric framework for a co-curricular research experience, the **Student Research Engagement Model**, is proposed for consideration.

Figure 1. Student Research Engagement Model



The first step for many STEM students is to begin working in a research lab doing support duties - washing dishes, cleaning cages, making chemical solutions, entering data into a spread sheet, or counting specimens in the field. Students become physically involved in the business of research and begin to acclimate themselves to a community of practice. They may shadow older students and provide assistance, but the intellectual engagement may be minimal. Although this time spent by the student is part of the continuum of the practice of undergraduate research, its lack of a deep engagement may not merit the educational definition of ‘undergraduate research’. This ‘exposure’ stage is termed **Research Involvement** in the proposed Student Research Engagement Model. This stage provides students opportunities to develop basic research skills appropriate to their discipline. It requires that a student have a supervisor and tasks to complete, but not necessarily anything beyond that. Because there is little academic investment, this type of involvement would not be appropriate for course credit. Undergraduates who partake in Research Involvement may use this exposure to test the waters for more in depth engagement. For STEM students who are also in need of an on-campus job, working in a lab serves two purposes: exposure to research and a salary. One might consider Research Involvement stage to be the individual experiential learning counterpart to formal research orientation classes that

expose students to topics and methods of research in their discipline.

The next three components of the Student Research Engagement Model are *additive* in nature, and depending on how the practice of undergraduate research is carried out in a particular institution, the student may immediately participate in the most holistic level, the **Research Program**, rather than needing to progress through each stage in a linear fashion.

Undergraduates who are engaged at the **Research Project** level may be assigned a part of an ongoing research project by the faculty mentor, perhaps a parallel project to a graduate student in the research team. Although the student has ownership of their component of the project, the student does not develop the experimental design or protocol, use his or her own creativity and ideas, and/or is not involved through the period of data analysis, drawing conclusions, and considering limitations and areas for future study. The student will have the opportunity to develop technical skills and good data management practices; however, the student may not be more than another set of lab hands for the purpose of increasing the quantity of data produced by the research team. The student will certainly learn valuable and transferable skills; however, the student may not have the full opportunity that the practice of undergraduate research activity can provide. A piece of a research project and a research mentor is the minimal required components for this stage; although, working in a group setting does not necessarily move the student into the Research Program stage. Inexperienced students who are just beginning to participate in a VIP team or integrated work/research experience may best describe their engagement as participation in a Research Project. At this level of engagement, there are no formal educational workshops or professional development opportunities offered beyond what the mentor can provide for the student.

The next level, the **Research Experience**, is broader in scope and deeper in engagement than the Research Project. The Research Project stage gives students a piece of their own project, in contrast to the proposed Research Experience stage where the student has the opportunity to experience a project from beginning to end. Even if they begin their experience with an ongoing experiment, due to the reiterative cycle that is the nature of scientific research, they will eventually experience the entire arc of a project. It is expected that the that a student will gain a deeper understanding of their research system through selecting and evaluating the primary literature, trouble shooting and problem solving, and doing data analysis and ultimately be responsible for the direction of their project. The expectation of a Research Experience also includes summarizing results, drawing conclusions, articulating ideas for future study, and presenting the findings to their mentor and/or research team in a written paper or oral presentation. Students should also have the opportunity to interact with their own 'community of practice' that is likely to be their (lab) research team and collaborating students and scientists. This may include lab meetings and journal clubs. Participating in the community of practice is an important aspect of professional socialization and identity formation as a researcher and should be what senior students in VIP teams realize through their engagement.

A student in the Research Experience level of engagement may not be purposeful about evaluating their work and progress, scientific knowledge, and professional development in a context beyond of their daily community of practice. To move their engagement into a broader circle, a program infrastructure is needed. Establishing an environment that supports program-

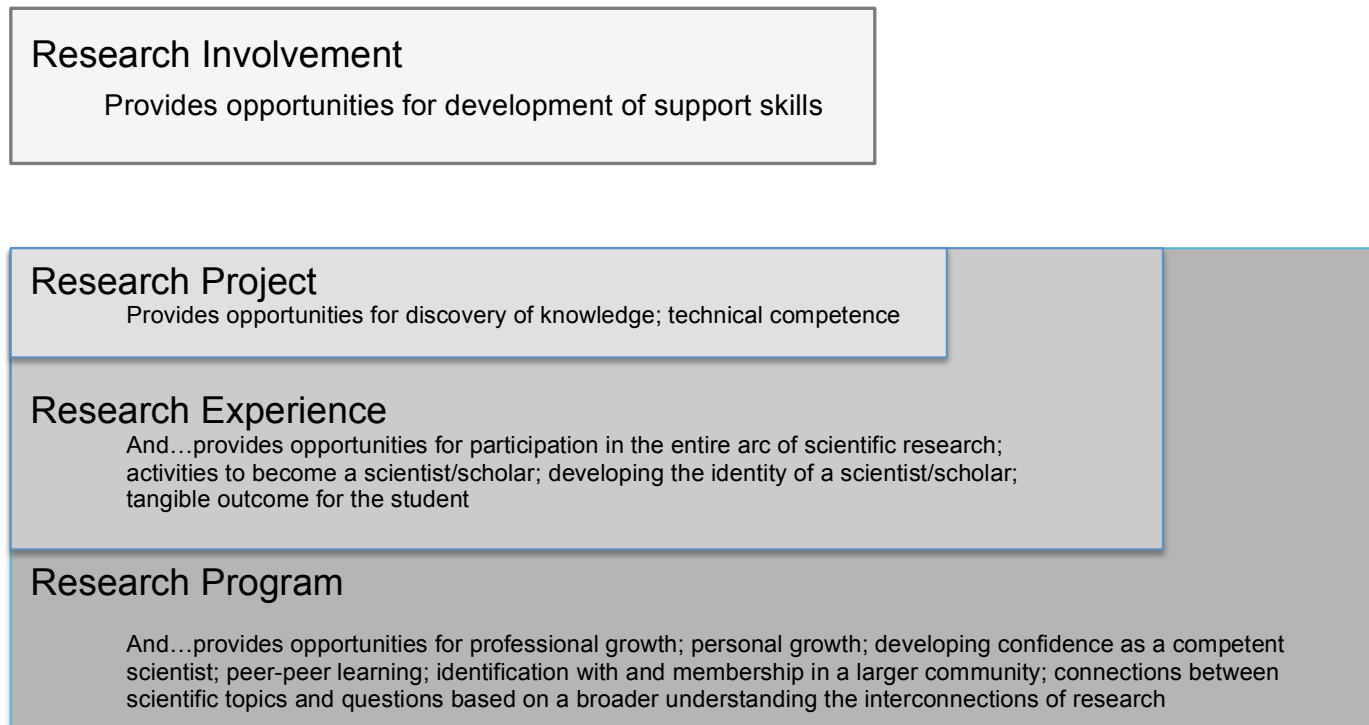
level planning and activities should help to maximize the potential of the high-impact educational practice. A program organized to ensure peer interaction, frequent feedback, and opportunities for reflection and professional development can enhance the activity of undergraduate research.

The term Program can be defined as a plan of action, a set of activities with a specific goal, or a system of services and opportunities coordinated to achieving a purpose. Often, the practice of undergraduate research is referred as ‘an undergraduate research program’, when the level of involvement is really at a project or experience level. In the Student Research Engagement Model, there are developmental goals beyond research skill mastery. The **Research Program** frames the opportunity as holistic for the student and promotes professional skills, personal growth, contextual understanding, and self-authorship. A Research Program includes ancillary activities and expectations beyond the immediate community of practice. Additionally, a Program includes opportunities for peer-peer learning which is a hallmark of high-impact educational practices. Opportunities should include professional and personal development learning (perhaps in the form of group workshops), presentations of research findings to audiences beyond one’s circle of research team members, feedback from others in addition to the research mentor, and self-evaluation. Peers can provide emotional and motivational support, aid in socialization and setting appropriate expectations, and share in the various research triumphs and trials students may be experiencing for the first time. Peers can help each other understand the social norms of research teams. Workshops and peer interaction can widen the horizons of students in regards to career opportunities and new areas of scientific exploration. Programs should also have an entry process (most likely a written application) that requires the student to articulate their personal and professional goals for participating, develop a research proposal, and anticipate research and learning outcomes. Although many summer programs for visiting interns do not require a research proposal prior to participation, good educational practice would suggest that undergraduates write a project statement as they are becoming oriented to their summer project. Programs should also require a summary outcome that may include an abstract, project poster, oral presentation, or research paper. These project artifacts should be shared to gain valuable experience in communicating and receiving feedback from someone in addition to their mentor. Although the typical end-of-program formal evaluation (usually a survey) completed by students benefits the sponsoring organization and staff coordinator, the activity also provides a structured opportunity for student self-reflection. The structure of a formal program ensures specific expectations for students, but should also include specific expectations for faculty mentors. These expectations may be outlined in mentor handbooks, mentor training, or socialization and identity of the mentor with the program community.

A purposeful program requires articulated goals and expectations, a peer community, and educational programming as well as an infrastructure to provide coordination for students and mentors. Although there is a cost associated with an infrastructure to support undergraduate research, the trade-offs include efficient use of resources, development of and identification with a program, expert knowledge for educational programming, and logistical coordination. A program infrastructure allows logistical responsibilities and common learning topics (making posters, responsible conduct of research education, basics of applying to graduate school) to be shifted from the faculty mentor to the program which, frees the faculty members to do what they are uniquely qualified to do – research and mentoring.

To summarize the additive nature of the Student Research Engagement Model, figure 2 provides a developmental framework of the stages and breadth of activities.

Figure 2. Student Research Engagement Model



Students can realize benefit at any stage of engagement; however, undergraduate research *programs* should strive to achieve a structure that maximizes the potential of the developing student in a holistic educational manner, beyond learning only technical skills. In addition to the growth of the student, the Research Program level has benefits for faculty members and institutions. Institutions that use the practice of undergraduate research as an intervention to increase retention or academic excellence may realize a greater benefit when students have peer learning experiences and strong identification with a purposeful community. The Program concept can be constructed to allow individual students working alone with a faculty member or with a small team to become part of a larger experience. Programs like SURI at Ohio State and the Meyerhoff Program exemplify this approach. Shared training, workshops, student symposia, networking, and social activities help to develop community and further the aspirational goals of undergraduate research. Undergraduate research program directors, committees, and agency grant panels can be instrumental in moving student opportunities from project-based engagement to an environment that promotes the benefits of a true program.

The NSF REU program proposal solicitation language (below) demonstrates an intuitive understanding of the aspiration of the Research Program framework. Text has been italicized to map with some of the concepts proposed in the Student Research Engagement Model:

“Research experience is one of the most effective avenues for attracting students to and retaining them in science and engineering, and for preparing them for careers in these

fields. The REU program, through both Sites and Supplements, aims to *provide appropriate and valuable educational experiences for undergraduate students through participation in research. REU projects involve students in meaningful ways in ongoing research programs or in research projects specifically designed for the REU program. REU projects feature high-quality interaction of students with faculty and/or other research mentors and access to appropriate facilities and professional development opportunities.*”

The Student Research Engagement Model also maps with likely qualities of “well done” high-impact educational practices. As co-curricular undergraduate research opportunities are evaluated, developed, and enhanced, the proposed model may serve as lens to complement the existing rubrics of student learning (such as those developed by George Mason University or Willison and O’Regan) and the guidelines provided by the COEUR document to establish institutional environments supportive of the practice of undergraduate research.

VII. Other Challenges & Recommendations

Many challenges have already been identified in this review. Refining the expectations and components of the practice of co-curricular undergraduate research continues to be a work in progress. Sorting through the variation of approaches and different enhancements of programs to determine effective practices is complex. A sizable number of sample programs located at or sponsored by colleges and universities, non-profit organizations, research facilities, and federal and private agencies have been mentioned throughout this review. However, this review only skims the surface of the opportunities that are available. Other agencies and sectors to explore include NOAA, Departments of Energy and Defense, and industries and start-up companies in the biotech, information sciences, and other technical disciplines. Social and behavioral sciences, quantitative sciences, applied agricultural and health sciences, and other physical sciences should be surveyed as well. Cataloging the variety of opportunities and disseminating this information to students and their advisors is a challenge. Encouraging discussions and idea sharing between institutions, agencies, and disciplines is a challenge; although some of the consortia highlighted in this review are modeling effective communication and collaboration toward shared goals.

The difficulties in documenting student participation and tracking student outcomes are major challenges. Participating in a co-curricular research experience is beneficial for student learning and development, and is essentially a requirement for entering a graduate STEM program; however, there is a gap in national data on the demographics and participation patterns of students. It is important to determine who is and who is not participating and what experiences are key to achieving desired outcomes for different populations of students. Institutional leaders, program directors, funding agencies, and policy makers need the work of educational researchers to provide insight; however, education researchers will first need assistance in identifying the populations of students to study and the variety of opportunities available. Because students may or may not register for credit, receive financial support, and/or participate in a formal program, there are many ways for students to be undercounted or double counted. A more detailed description of the nuances of the problem can be found in the Spring 2012 issue of the *CUR Quarterly* and specifically in the guest editorial (Blockus, 2012). Without information on which students participate in research (and where, when, and how), we cannot determine if there is socioeconomic and racial equity in participation or more fully understand barriers to

participation for students from a variety of backgrounds.

Tracking students and their accomplishments after participation and graduation is another challenge for institutions and agencies. The advent of social media makes the job of finding students easier, although is still time consuming. To be productive in tracking students, resources must be allocated to make the task an integral piece of the permanent infrastructure. Smaller programs and programs where students feel a strong affinity to the program seem to have an easier time keeping in touch with students as they scatter across the country to pursue advance degrees, enter the workforce, or switch out of STEM careers. Some consortia managed to establish effective tracking systems. At the federal level, the McNair Scholars Program has an effective and detailed reporting system that may serve as a model. Another layer of complexity is that students may participate in more than one program or receive funding from more than one source over their undergraduate career. Care must be taken not to double-count a PhD student who may have been in a series of programs such as a campus fellowship, a summer at NASA, and as a McNair Scholar during their senior year. Determining the number of publications or conference presentations that these students have produced is also a challenge.

Recommendations for education and science leaders for systemic improvements

- Continue dialogue to better define the practice of undergraduate research, strive for consensus on education and developmental outcomes, develop operational definitions of success (for students, for programs/institutions, for mentors, for agencies), develop a taxonomy of variations of opportunities and experiences to continue discussion with shared definitions.
- Develop better systems to catalog opportunities across institutional types, scientific disciplines, and funding agencies.
 - A comprehensive listing will serve students and allow for more effective dissemination of opportunities.
 - A comprehensive listing of opportunities will inform educational researchers and policy makers about the quality and variety of undergraduate researcher “slots” available.
 - Identifying leaders and directors of the variety of opportunities will aid in sharing best practices, compare student compensation methods, and promote standards of practice.
- Develop a comprehensive, multi-institutional approach to identifying students participating in co-curricular research opportunities in summer and other “off-campus” programs.
 - Data on student participation can be used to analyze demographics to better understand access issues/barriers to participation, disciplinary differences, trends in engaging underclassmen, and information on students participating in more than one opportunity.
 - Identifying participants will aid education researchers in studying learning outcomes and making comparisons between variations of programs.
 - Identifying participants is needed to track outcomes (education, career, research productivity including publications and conference attendance).
- Develop and share effective methods to track student educational and research outcomes; Strategize approaches to share data.
- Review recommendations from educational researchers and experienced undergraduate research program directors to establish standards of practice.

- Establish lines of communication and opportunities to share data and best practices between agencies, organizations, institutions, societies, education researchers, and the scientific community.
 - Share best practices for programming, infrastructure, data collection and evaluation approaches.
 - Discuss opportunities for purposeful collaboration and coordination for recruitment, student tracking, and evaluation to reduce redundancy and maximize resources.
 - Promote communication and collaboration is *across* scientific disciplines and organization sectors.

Recommendations for institutions and organizations

- Continue to develop structures to assist in documenting student participation, including students participating in multiple opportunities.
- Continue to develop structures to assist in tracking student outcomes.
- Build the expectation that all upper class student researchers have the opportunity to participate in a “Research Program” to maximize developmental impact; Invest in infrastructure as needed.
- Consider where there may be duplication of infrastructure and programming efforts within the institution; Invest in infrastructure or realignment as needed.
- Explore new models of co-curricular opportunities and implement as appropriate to campus goals and culture.
- Encourage use of learning rubrics, developed for undergraduate research, by mentors and students to promote feedback and student development.

Recommendations for educational researchers

- Identify and review effective consortia and multi-institution/location programs that are collaborative or coordinated to:
 - Report on students served and student outcomes.
 - Identify characteristics of successful consortia and coordinated programs.
 - Compare outcomes and efficiencies of consortia/coordinated programs with other programs.
 - Make recommendation on the efficacy of the development of more consortia.
- Identify, describe, and review variations in first year programs and team approaches (VIP, work/integration) as co-curricular opportunities.
- Examine the variations in experiences and outcomes of students participating in different levels of the Student Research Engagement Model or other similar frameworks that describe the complexities of the undergraduate research opportunity as experienced by the student.
- Compare outcomes of new models (first year programs, team approaches) with both traditional individualized scholarly activities (with and without Research Program elements) and CURE experiences.
- Examine the practice of undergraduate research from a student-centered perspective, including impact of ‘on-ramping’ programs, structured programs/workshops, use of learning rubrics by mentors to help students map their development, and participation in multiple programs

Recommendation for societies and others sponsoring student opportunities

- Request that individually funded students participate in a Research Program as a condition of their funding to maximize student development.
- Share information on supported students with a point person at their home university responsible for documenting participation.
- Participate in on-going discussions and collaborations to promote best practices.
- Identify undergraduate students attending and/or presenting at society-sponsored regional, national and international conferences. Track participation over time and share information on participation and best practices. Provide networking and professional development opportunities specific to undergraduate researchers.

Undergraduate research has been demonstrated to transform the student learning experience, expand opportunities for advanced degrees and scientific careers, and aid in the production of new knowledge. Possibly more than any of the other identified high-impact educational practices, undergraduate research has the potential to transform the workforce to be inclusive of underrepresented and disadvantaged students and catalyze the nations economic development through scientific research. However, there are steps that need to be taken to ensure equal participation, reach maximum impact, enhance efficiency, and work together for a common good.

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Appendix A. Examples of Listings of Summer Research Programs

University of California-Irvine – database of more than 400 listings
www.urop.uci.edu/opportunities.html

American Mathematical Society – more than 100 listings
www.ams.org/programs/students/emp-reu

American Mathematical Society: MathPrograms.Org – common application site for participating math programs
www.mathprograms.org

American Society for Biochemistry and Molecular Biology – listings state by state
www.asbmb.org/SummerResearch/

American Chemical Society
www.acs.org/content/acs/en/education/students/college/research.html

College of the Holy Cross - listing of listings
holycross.edu/office-science-coordinator/campus-summer-science-research-opportunities-2016

NSF Research Experiences for Undergraduates site program listing
www.nsf.gov/crssprgm/reu/reu_search.cfm

George Mason University – listing of listings
oscar.gmu.edu/students/Summer-Opportunities.cfm

Faculty for Undergraduate Neuroscience (FUN) – more than 75 listings
www.funfaculty.org/drupal/undergrad_internships_neuroscience

Rochester Institute of Technology
people.rit.edu/gtfsbi/Symp/summer.htm

Institute for Broadening Participation (Pathways to Science project) – more than 750 listings
www.pathwaystoscience.org/

Association American of Medical Colleges (Group on Graduate Research, Education & Training – GREAT Group)
– 70 summer research programs at medical colleges
www.aamc.org/members/great/61052/great_summerlinks.html

Marine Careers (sponsored by the New Hampshire Sea Grant program) – 30 programs for K-12 and college students
www.marinecareers.net/summer

Appendix B. Sampling of consortia that support the practice of co-curricular undergraduate research

Keck Geology Consortium (www.keckgeology.org) - The Consortium began in 1987 with the collaboration of private liberal arts college faculty interesting in pooling resources and opportunities for field and lab research in the geological sciences. The Consortium now has 18 member institutions and has been successful in securing funding from Exxon and NSF. Students apply to participate in summer research teams of 5-8 students and 2 or more collaborating faculty. In addition to field sites in North America, many teams travel abroad gaining both geology research experience and exposure to other cultures. Funding from NSF has enabled a greater diversity of student participants from underrepresented backgrounds and non-member institutions, as well as underclassmen. In a typical summer there are six projects, two of which are earmarked for underclassmen. A key feature of the program is the annual Keck Symposium, hosted each April by a different member institution. Students present posters and attend workshops, while faculty mentors have opportunities to sustain their research collaborations and discuss best practices. Over the past two and a half decades, more than 1400 students have participated in the Keck program. A detailed history of the program and research project descriptions can be found at the Keck Geology Consortium website.

Center for Undergraduate Research in Mathematics – CURM (curm.byu.edu/) – CURM provides an interesting model to expand the practice of undergraduate research in the mathematical sciences. Each summer, ~16 mathematics faculty gather for a 3-day professional workshop to prepare to mentor teams of 2-5 undergraduates during the academic year at their home institution (~45 students/year). Funding is provided by CURM to the faculty/home institution to reduce the teaching load of the mentor and students receive a \$3000 stipend. All participants gather at an annual CURM meeting and students and faculty are encouraged to attend other regional and national professional conferences. According to the CURM website, ~350 students (27% minority, 52% female) and more than 100 faculty have participated in the program. The major source of funding for CURM is NSF. CURM was recognized by the American Mathematical Society in 2015 for its impact on efforts to promote the study of mathematics to underrepresented students.

The Leadership Alliance (www.theleadershipalliance.org) - The Leadership Alliance was begun in 1992 with 23 member institutions. The current 35 institutional members include research institutions (including all members of the Ivy League, Chicago, Stanford, Virginia, and NYU), HBCUs (such as Howard, Xavier, Spelman), and institutions with strong numbers of underrepresented students in STEM disciplines (including UMBC, NC A&T, University of Puerto Rico). The goal of the alliance is to increase the number of underrepresented students in graduate programs to develop the students for leadership positions in academia, industry, and the public sector. Although there is a heavy STEM focus, opportunities are available for students in the humanities and social sciences. The signature program of the Leadership Alliance is the Summer Research Early Identification Program (SR-EIP) which provides access to undergraduate research internships for almost 300 students per year at 22 Alliance institutions. Students from any institution can apply for up to three institutions through a common application. Each institution coordinates and funds their own program. The National Symposium is held at the end of the summer for more than 600 undergraduate interns, Alliance member faculty, and

program alumni (in graduate school or who have finished advanced degrees). The Leadership Alliance reports that more than 700 program alumni have completed terminal degrees. The Doctoral Scholars program and newly established alumni organization are essential to the networking mission of the Alliance. A newly established First Year Research Experience (FYRE) initiative aims to encourage best practices among Leadership Alliance institutions. Additional information, including demographic data, can be found on the Leadership Alliance website.

Committee on Institutional Cooperation – CIC (www.cic.net) - The CIC was established as the academic counterpart to the Big Ten athletic league and currently includes the expanded roster of 14 Big Ten institutions, as well as the University of Chicago. Among the many academic and research programs for faculty and students is the Summer Research Opportunities Program (SROP). CIC maintains a common application portal for undergraduate applications to various summer programs at all 15 CIC institutions. Students from non-CIC institutions may apply. The variety of disciplines, funding and benefits, and programming is set by each institution and program. SROP provides a convenience to CIC institutions to help them increase interest in their graduate programs. With a 30 year history, the CIC SROP website reports that more than 600 SROP alumni have earned PhDs.

Amgen Scholars (amgenscholars.com) – The Amgen Scholars Program is funded by the Amgen Foundation, the philanthropic arm of the multinational biopharmaceutical company. The program provides financial support for 200-250 undergraduates each year to conduct summer research at selected premier universities and NIH with the goal of promoting scientific careers. There is a counterpart program at five European sites (for European students) and a program at two Japanese universities open to students from across the globe. Since 2007, more than 2800 students have participated in the program and close to 1000 are in or have completed PhDs or MD/PhDs. Supported disciplines are in the biomedical sciences, chemistry, cell and molecular biology, and related sciences including bioinformatics and statistics. The Amgen Scholars Program provides a coordinated website; however, each host site has their own application process, sets their own dates and student benefits, and organizes their own programming. Professional development, exposure to industry careers, and networking are priorities of the annual Amgen Scholars Symposia held each summer in California, near the Amgen's headquarters. Current host institutions include Cal Tech, MIT, Harvard, UCLA, Stanford and five other universities and NIH.

Howard Hughes Medical Institute Exceptional Research Opportunities Program – EXROP - (<http://www.hhmi.org/programs/exceptional-research-opportunities-program>) - EXROP was established by HHMI to diversify the next generation of scientists. It brings together outstanding undergraduates (nominated by HHMI-funded educational program directors, HHMI research professors, or from a Science Education Alliance school) and pairs the selected students with HHMI research professors across the country for a summer research experience. Student applications and matching with HHMI professors are coordinated by HHMI staff. Local arrangements and educational programming occurs as appropriate to the HHMI mentor's institution. Although not a true consortium, the commonalities are a target audience of outstanding underrepresented students from institutions with some connection to existing HHMI funding and high profile HHMI professors serving as mentors. Approximately 70 students/year

are selected and participate in a student conference at HHMI facilities in May before their experience and return a year later for a follow-up meeting. The professional development and networking at the May conference is a purposeful component of the program. HHMI has recently begun offering a second summer of funding for qualified EXROP students to continue their research at an accelerated pace in the same HHMI lab. According to the HHMI website, approximately 45% of alumni enter graduate programs.

Appendix C. Sampling of federal agency programs that support the practice of co-curricular undergraduate research

National Science Foundation

A brief description of the NSF Research Experiences for Undergraduates (REU) program can be found in Chapter 12 of Kinkead and Blockus (2012). Each summer ~500 REU Site programs accept an average of 9-10 students for an estimated total of 4750 students per year (C. Hovis, personal communication). Information is not easily available on the number of positions per scientific discipline, type of institutions receiving funds, or demographic breakdown of students. The most recent demographic and outcome summary data is provided in Russell, Hancock, and McCullough (2007). Tracking student educational outcomes continues to be a challenge. Although the REU program is funded in all scientific areas across NSF, each area allocates its own budget. Additionally, PI's of REU grants in a discipline may initiate common applications, data sharing, and common evaluation plans; however, the level of coordination and community varies by discipline. The REU Site program solicitation has been encouraging support of freshmen and sophomore students. REU Supplements to NSF research grants are awarded on a case by case basis to NSF PIs to fund individual undergraduates. In a typical year, 1800 supplements have been awarded to support approximately 3500 undergraduates.

There are a number of other long-standing NSF programs that are purposeful in supporting undergraduate researchers. These include the Louis Stokes Alliances for Minority Participation, Centers of Research Excellence in Science and Technology, Science and Technology Centers, Engineering Research Centers, and International Research Experiences for Students.

National Institutes of Health

A brief description of programs administered by NIGMS can be found in Chapter 12 of Kinkead and Blockus (2012). Since 2012, segments of NIGMS have been reorganized and renamed, and now these programs fall under the pre-doctoral training branch of the Division of Training, Workforce Development, and Diversity (TWD). Acronyms of relevant undergraduate programs in TWD include Bridges, IMSD, MARC U-STAR, and RISE. Information provided on the website (www.nigms.nih.gov/Training/Pages/TWDPrograms.aspx) provides a listing of the number of institutions receiving funds in each program in FY 2015 and the number of students supported through those programs. A total of 2327 undergraduates directly benefited from these programs:

- Bridges to the Baccalaureate – 44 institutions, 496 positions
- Initiative for Maximizing Student Development – 49 institutions, 523 undergraduates
- MARC Undergraduate Student Training in Academic Research – 43 institutions, 553 trainees
- Research Initiative for Scientific Enhancement – 49 institutions, 755 undergraduates

Institutions may have multiple sources of TWD funding, including additional programs at the graduate and post-doctoral level. Some institutions, such as the University of Kansas, have strategically co-located administrative responsibility for these programs in one office to create a multi-level community and share resources (odst.ku.edu/). Louisiana State University has combined TWD-funded programs with other externally funded programs such as LSAMP and Upward Bound for the same purpose and effect (sites01.lsu.edu/wp/osi/).

Department of Agriculture

The USDA National Institute of Food and Agriculture has just begun a competitive grant program for colleges and universities titled *Research and Extension Experiential Learning for Undergraduates (REEU) Fellowships* through the Food, Agriculture, Natural Resources and Human Sciences Education and Literacy Initiative (<http://nifa.usda.gov/funding-opportunity/agriculture-and-food-research-initiative-food-agriculture-natural-resources-and>). The program requires hands-on experiences in targeted USDA areas and includes participation in extension activities as well as research. Examples of priority areas include climate variability and change, childhood obesity prevention, food safety and security, plant sciences, animal sciences, bioenergy, and water resources. The REEU program appears to be modeled after the NSF REU site program, with the exception that the program must be integrated across at least two of three experiences: research, education, and extension. One of the goals of the REEU program is to develop the next generation agricultural workforce including highlighting careers in extension at land-grant colleges and universities. Therefore, students participating in this program will gain exposure to career options and develop leadership skills in addition to conducting research. There is an emphasis on recruiting underrepresented minority students and early-stage college students and a limit that no more than 50% of the interns from will be from the host institution. Proposals for the first round of funding (2015 deadline) are awaiting finalization with a second round of proposal submissions currently underway (March 2016 deadline).

Department of Education

The McNair Postbaccalaureate Achievement Program, a TRIO program funded through the Department of Education, targets students from disadvantaged backgrounds to move them towards doctoral degree attainment. The McNair Program has done an excellent job of annual data collection and making annual data accessible. In 2015, there were 151 active programs that served 4,293 students at an average program cost of \$8,316 per student. There is a mandated stipend amount of \$2800 per student for one year and the program will also provide conference travel and consumable supplies. One can easily find annual data on graduation rates and other outcome data on the program website (<http://www2.ed.gov/programs/triomcnair>); although the last “Facts and Figures” report is from 2002-2005. This report provides a summary of the types of institutions awarded McNair funds (e.g., 18% of awards went to minority serving institutions; 23% of awards went to private institutions) and demographic breakdowns of participating students (gender, first generation/low income, race/ethnicity). The McNair Program is not specific to STEM disciplines; however, recent annual reports have collected data on student disciplines, therefore information on percent of STEM students should be available. Most of the programs run as a summer experience, although this is not a requirement. The reported average of 28 students per institution is a bit misleading because it includes currently funded McNair

researchers as well as students who completed their funded McNair research projects, but have not yet graduated. The reporting system is now requesting information to determine if undergraduates are continuing with research after McNair, and if they are being supported by other federal funds. The burden of reporting and following up on graduate school status falls upon each individual campus and may take up to 120 hrs/year of staff time to collect the data and complete the extensive report; however, the wealth of data collected by the Department of Education is commendable and should serve as a model for other agencies.

National Aeronautics and Space Administration

In 2010, NASA designed a One Stop Shopping Initiative (OSSI) web portal for internships, fellowships, and scholarships for students from high school through doctoral degrees (<https://intern.nasa.gov> and B. Dansberry and F. Prochaska, personal communication). OSSI is one of a number of initiatives to refocus and streamline educational programs at NASA in the past decade. With the OSSI system, NASA-sponsored research mentors can post positions and screen student applications. Students can submit their applications and search for opportunities at more than a dozen NASA Centers. The standard summer stipend for 10 weeks is \$6000 and may be supplemented with travel and/or housing allowances. Approximately 75% of the ~1500 positions are summer internships. Most students will have an integrated work/research experience with a team of professionals under the tutelage of a single mentor, in contrast to NSF REU programs where students tend to have projects that are more individual in nature. There is a desire to provide more than one 10 week experience for undergraduates, as it can be difficult to break into the space/aerospace sciences without multiple co-ops or longer experiences. Therefore, like many other agencies and programs, there is a move to encourage applications from underclassmen. Undergraduate research may also be supported through colleges and universities that receive NASA Space Grant Consortium funding. The nature of the educational programs supported by Space Grants are determined by the individual state consortiums.