

BEACON Center for the Study of Evolution in Action
An NSF Science and Technology Center
Strategic Implementation Plan
(updated October 2013)

EXECUTIVE SUMMARY

The BEACON Center for the Study of Evolution in Action is an NSF Science and Technology Center founded with the **mission** of illuminating and harnessing the power of evolution in action to advance science and technology and benefit society. BEACON is a consortium of universities led by Michigan State University, with partner institutions of North Carolina A&T State University, the University of Idaho, the University of Texas at Austin, and the University of Washington. BEACON unites biologists, computer scientists and engineers in joint study of natural and artificial evolutionary processes and in harnessing them to solve real-world problems. Developers of evolutionary algorithms have long borrowed high-level concepts from biology to improve problem-solving methods, but have not captured the nuances of evolutionary theory. Likewise, studying the evolution of artificial systems can provide biologists with insight into the dynamics of the evolutionary process and the critical factors underlying emergent properties and behaviors. BEACON will promote the transfer of discoveries from biology into computer science and engineering design, while using novel computational methods and artificial evolutionary systems to address complex biological questions that are difficult or impossible to study with natural organisms.

As Dobzhansky famously noted, “Nothing in biology makes sense except in the light of evolution.” BEACON’s **vision** focuses that light, revealing fundamental biological concepts and illuminating the path toward computational applications. The key insight underlying the Center is that transformative discoveries in both computing and biology are possible through studying evolution *as it happens*, in both natural and digital domains. The philosopher Dennett (2002) has pointed out the algorithmic nature of evolution as a process that will occur in any system with “replication, variation (mutation) and differential fitness (competition).” BEACON aims to understand evolution in this universal framework.

In this updated Strategic Plan, we present **Goal Statements** for six areas: Education, Human Resources, and Diversity (EHRD), Leadership and Management, Knowledge Transfer, Integrative Research, Ethics, and Research Output. For each goal, we have identified two to six **Optimal Outcomes**, and we will measure our progress towards these outcomes using Specific, Measurable, Attainable, Relevant and Time-Bound (**SMART Targets**). For each Optimal Outcome, we also identify potential **Barriers to Success**, and the **Mitigating Actions** we will take to overcome these barriers. For each Mitigating Action and additional specific **Actions** relevant to each Outcome, we identify who will serve as a **Point of Contact**, and the **Due Date** for the action.

Summary of Goals. BEACON’s **Education, Human Resources, and Diversity (EHRD) overarching goal** is to integrate cutting-edge, multidisciplinary research, education, and outreach efforts across the Center that will advance innovative training, the diversity of the Center and scientific workforce, and public education to promote greater understanding of

evolution and the nature of science. BEACON's **Leadership and Management goals** are to envision and enable the Center's mission through inclusive and transparent decision-making as well as effective and responsible implementation; to inspire Center participants; and to facilitate collaborative efforts within and beyond the Center. BEACON's **Knowledge Transfer goal** is to develop effective mechanisms and pathways to facilitate intellectual exchanges among BEACON partners and industrial affiliates that will support the sharing of knowledge and application of new technology. BEACON's **Integrative Research Goal** is to produce transformative, synergistic research through an inclusive collaborative culture that crosses disciplinary and institutional boundaries and is embedded throughout the Center's activities. BEACON's **Ethics Goal** is to practice and promote ethical and responsible research by implementing cross-disciplinary and multi-institutional ethics programs that will inform and guide all participants of the Center. BEACON's **research output goal** is to disseminate widely an increasing quantity of original and highly regarded scientific research on evolution in action.

EDUCATION, HUMAN RESOURCES, AND DIVERSITY PLAN

BEACON's **Education, Human Resources, and Diversity (EHRD) overarching goal** is to integrate cutting-edge, multidisciplinary research, education, and outreach efforts across the Center that will advance innovative training, the diversity of the Center and scientific workforce, and public education to promote greater understanding of evolution and the nature of science. We are approaching this goal in two ways: by educating a diverse new generation of interdisciplinary scientists and engineers, and through outreach to the K-16 community and the general public. BEACON will contribute to the pressing national need to bolster U.S. pre-eminence in science and technology by educating people about the importance of understanding, managing and harnessing biological and computational evolutionary processes.

EHRD Optimal Outcome 1: Multidisciplinary Ph.D. graduates and post-docs placed in faculty positions in line with averages across engineering, computer science, and biology. BEACON provides multidisciplinary training for graduate students and post-docs, and works to increase their visibility in biology and computer science disciplines. BEACON graduate students come from many departments, colleges and partner universities, each with their own disciplinary requirements and benchmarks. BEACON does not supersede these, but operates instead as an interdisciplinary enrichment program.

We are accomplishing this outcome through an integrated **sequence of courses** to prepare graduate students for this new multidisciplinary research. These courses are now available at all five partner institutions. In the fall semester, new engineering and computer science students take evolutionary biology, while biology students take a course in computational science; each group learns evolutionary theory and application from the perspective of the other. These courses have been taught at MSU for three years in a row now (Computational Science for Evolutionary Biologists, CSE 801, taught by C. Titus Brown; Evolutionary Biology for Non-Life Scientists, ZOL 890-601, taught by Louise Mead in 2013). These courses are also offered simultaneously at multiple partner institutions (UI, UT, UW) using distance learning technology.

In line with broadly training our graduate students, and maximizing the impact of these courses, we continue to respond to user and consortium needs.

In 2013, Mead's ZOL 890-601 course had two BEACON graduate students as co-instructors: Caroline Turner (Microbiology and Molecular Genetics) and Emily Weigel (Dept. of Zoology, joint Ph.D. with Ecology, Evolutionary Biology and Behavior Program). Both Turner and Weigel took the BEACON series of courses for biology students early in their graduate programs, and understand the challenges faced by our students. Turner and Weigel also gain valuable professional development experience as they are responsible for the creation, development, and instruction of a course that requires teaching concepts of evolution to students not classically trained as biologists.

In 2013, Brown's CSE 801 course was also restructured in order to improve the logistics of participation at BEACON's partner institutions AND to serve the needs of more biologists. Early in the semester, Brown and a teaching assistant taught an intensive, multi-day on-site workshop at MSU, followed by a similar on-site workshop at University of Washington, where the quarter

starts nearly a month later than the semester starts at MSU and the other partner universities. Then the remainder of the course is offered for MSU, UW, UTA and UI during the remainder of the quarter/semester after the workshops are completed. BEACON students follow with the remainder of the core curriculum, with more students able to participate in the course now that schedules allow. The intensive onsite workshops also provides an opportunity for Brown to train many more biologists in use of modern computing tools and cyberinfrastructure than would be possible through the full semester-long course, including many postdocs and faculty members. As an example, the workshop at MSU in September had 50 participants, and the workshop at UW had more people sign up than could be accommodated (>60). Under supplemental funding from NSF, and in response to feedback from the Site Report last year, Brown is developing material and training procedures with several partner centers so that such training can be made available broadly across the country.

The spring semester course (Interdisciplinary Research Methods with Evolution in Action, usually taught by Charles Ofria and Ian Dworkin, and taught by Dworkin and Chris Adami in spring, 2013, during Ofria's sabbatical leave) brings computational and engineering students together with biology students. As part of the course, students form multidisciplinary teams, under the joint supervision of computer science and biology faculty. Graduate students learn to use state-of-the-art tools to conduct their research and to facilitate long-distance collaboration across partner institutions.

Beginning fall 2011, the two first-semester classes have been offered for upper-level undergraduates and beginning graduate students at NC A&T, taught by Joseph Graves and Gerry Dozier; an integrated course was also offered in the spring, 2012 and 2013.

To facilitate the placement of a new generation of interdisciplinary scientists, BEACON must not only train these individuals but also promote them within traditional fields. We are accomplishing this goal by nominating BEACON students and scientists for awards and leadership positions within traditional disciplines (evolutionary biology, computational biology, computer science, engineering, etc.), and also by increasing BEACON-sponsored participation within society meetings (e.g., the annual Evolution meetings) and by hosting of society workshops/meetings at BEACON or co-organizing such meetings at other locations.

We provide resources and training in professional development for our graduate students. The BEACON Congress now includes a day-long retreat for our graduate students and postdocs. Graduate students are also taking advantage of programs across our campuses such as the FAST Fellows (Future Academic Scholars in Teaching) program at MSU.

We have also raised the prominence of BEACON within the computer science community by sponsoring BEACON booths, where we highlight BEACON participants, accomplishments and opportunities, at the two largest conferences in the field, the Genetic and Evolutionary Computation Conference (GECCO) and the Conference on Evolutionary Computation (CEC), in both 2012 and 2013. Goodman has also accepted a position on the Awards Committee of ACM's Special Interest Group for Evolutionary Computation (SIGEVO).

The completion of the transition of Prof. Kalyanmoy Deb from IIT Kanpur to BEACON at MSU

as the Koenig Endowed Chair in the Department of Electrical and Computer Engineering also brings a great deal of prestige to graduate students who will receive their education at BEACON. Prof. Deb has received three major international honors since January, 2012 and his reputation reflects very favorably on BEACON.

We will measure our progress towards this outcome by tracking the *fraction of BEACON graduate students and post-docs receiving offers of positions that integrate their interdisciplinary training*, to include positions as tenure track faculty, postdoctoral researcher, industrial affiliate, K-14 STEM education specialist, faculty administrator, science communication specialist, or advocate/political activist.

EHRD Optimal Outcome 2: Exceed national norms for diversity at all levels in the Center. The initial senior personnel at the Center are diverse, including eighteen women (25%), eight African Americans (11%), and one Hispanic (1%). Many of the participants have a history of mentoring women and minority students, and the proportion of BEACON graduate students that are women or minorities is currently at the national norms for women and Hispanics, and exceeds the national norms for Black Non-Hispanic graduate students. Our goal is to increase the diversity at the Center above our starting baseline.

Our first goal was to collect the baseline data for our diversity measure. We collected data on the *numbers or percentages of faculty, post-docs, graduate students, undergraduate participants, that are from underrepresented demographic groups*, including women, underrepresented ethnic groups, and people with disabilities. Our target is to achieve a 5% increase by October 2013 (this goal has been met), and a 10% increase by October 2015 over a baseline set by current national statistics for BEACON's disciplines, as documented by NSF.

Diversity is already an explicit factor in all funding decisions. Furthermore, Diversity Director Judi Brown Clarke developed a Faculty Affiliates Initiative targeted at recruiting diverse BEACON faculty partners at non-member institutions. The first Faculty Affiliate was appointed in April 2012, our second, in spring 2013, and additional affiliates will be appointed on an annual basis.

We will solicit feedback from the *External Advisory Committee* to get an objective assessment of our progress towards this goal.

EHRD Optimal Outcome 3: Increased literacy in evolution and the nature of science. BEACON's focus on *evolution in action* and pragmatic applications of evolutionary science puts us in a unique position to overcome common misconceptions about evolution and to demonstrate both its scientific significance and its practical and economic utility.

BEACON is developing tools and materials for education, such as the ongoing redevelopment of Avida-ED, implementation of evolutionary games within museum exhibits, and other educational materials. We are working with multiple public learning institutions, including the MSU Museum, the Texas Natural Science Center, and the Seattle Aquarium to offer these interactive exhibits, learning opportunities, and undergraduate research opportunities. All tool and material development goes through a rigorous process of vetting by content and grade-level

specialists and we are working with educational research partners to evaluate and assess the effectiveness as identified in our goals.

Avida-ED. We are building on the success of our Avida-ED digital evolution project (Pennock, Ofria, Lenski) by incorporating it into undergraduate biology courses throughout the partnership. We have extended topics covered and lessons available. Amy Lark, a graduate student in the College of Education at MSU and funded by BEACON, is carrying out a multi-case national-level study of Avida-ED. Her results suggest Avida-ED may increase both acceptance and understanding of evolution. Avida-ED pedagogy workshops for faculty have been held at all partner universities. We have also presented Avida-ED at a number of conferences (Society for the Study of Evolution, National Association of Biology Teachers). Our original goal was to complete the alignment of Avida and Avida-ED for additional flexibility by June 2011; however, the process is more time-consuming than expected. Alignment for the Mac is complete. Development of the PC version is proving more difficult but in progress, with an anticipated completion date of May, 2014.

We are also working closely with the National Center for Evolutionary Synthesis as well as the National Association Biology Teachers to bring our educational materials to a national audience, as well as support continued outreach to the entire evolution education community. For example, we are collaborating with NESCent to host the Evolution Symposium at the NABT Professional Development Conference in November 2013, and supporting a total of 4 community college and high school teachers as “Evolution Scholars” to attend the meeting. Goals of all our education and outreach are to deepen students’ understanding of evolution-related challenges, such as responding to the evolution of infectious diseases and limiting the evolution of antibiotic and pesticide resistance, and help them learn to protect the integrity of the scientific process.

EHRD Optimal Outcome 4: An increased interest in STEM careers in both academia and industry. As a Science and Technology Center focused on interdisciplinary research, we can show students STEM options and pathways through programs and learning opportunities.

BEACON will broaden participation in STEM disciplines by introducing students and teachers, especially from underrepresented groups, to the new opportunities afforded by BEACON’s applied evolutionary tools and research programs. Three programs that support this goal are the Summer Research Opportunity Program (SROP), BEACON Research Experiences for Undergraduates (REUs) at Kellogg Biological Station and Friday Harbor Laboratories, and the BEACON High School Summer Residential Program. BEACON also has education and outreach graduate RAs to interact with teachers and scientists to develop K-12 content.

BEACON High School Summer Residential Program. MSU’s College of Engineering Recruitment, Scholarships, and K-12 Outreach Office (Drew Kim) has developed and annually promotes a number of successful and growing STEM educational initiatives. Building on these successful programs, Kim offered the first one-week BEACON High School Summer Residential Program in summer 2011, a short course on study of evolution in action, including computer programming and various other types of engineering skills, taught by BEACON and other College of Engineering faculty and staff. The program has been repeated every summer since, and will continue. Tools developed and tested with these students will eventually be made

available for broader use at the high school level. Our goal for 2014 will be to seek to make this program align more closely with recruiting of undergraduates for MSU's planned new Bioengineering Department, in which students will benefit from both biological and engineering training experiences in the summer program.

We are measuring our progress toward achieving this outcome using *pre- and post-program survey instruments* to assess the proportion of participants expressing interest in STEM careers. These surveys will be administered to groups participating in our programs. Our goal is to generate a significant increase in interest among participants in our programs. We will also solicit feedback from the External Advisory Committee to get an objective assessment of our progress towards this goal.

LEADERSHIP AND MANAGEMENT PLAN

BEACON's **Leadership and Management goals** are to envision and enable the Center's mission through inclusive and transparent decision-making as well as effective and responsible implementation; to inspire Center participants; and to facilitate collaborative efforts within and beyond the Center.

L&M Optimal Outcome 1. Increase in cross-disciplinary research and education. Historically, true interdisciplinary research and education has been hampered by field-specific terminology, methodology, and traditions, but especially by a lack of communication. BEACON is overcoming this barrier by facilitating communication among scientists, cross-training a new generation of graduate students, and encouraging the submission of interdisciplinary publications and proposals for funding. Technological systems for finding collaborators/mentors/students and tracking outputs and RCR training were put in place in December 2010 and refined throughout 2011, which greatly facilitates collaboration.

We have developed four measures to monitor our progress with this outcome:

- *Number of paper/conference submissions by BEACON authors.* In the short term, we aim to have 20 submissions/year on interdisciplinary research by BEACON authors; in the long term we anticipate at least 100 accepted peer-reviewed publications by October 2015. This goal is being met annually.
- *Number of new interdisciplinary courses.* In the first year, three new interdisciplinary courses were introduced at MSU. In the short term, we are aiming to offer joint/related courses at BEACON partner institutions. In the long term, our goal is for one additional course to be offered every other year throughout BEACON. One new course was offered at MSU in Fall 2011 (Evolutionary Computation, taught by Kalyanmoy Deb). He has offered a second new course, Evolutionary Multi-Objective Optimization, in fall of 2012 and fall of 2013.
- *Number of students enrolled in cross-disciplinary courses.* Our original short-term goal was 20 students across all five partner institutions per academic year. This goal was met in initial years, as there was a "backlog" of graduate students that had begun graduate study before BEACON's founding. However, most of these students have now taken these courses, and there are not enough new BEACON graduate students beginning studies without the relevant cross-disciplinary background to meet these numbers every year. Therefore, we are revising this goal to more closely match the numbers of new students enrolling each year, and to account for the fact that an increasing number of new graduate students already have an interdisciplinary background in biology and computer science (e.g., students who were involved in BEACON undergraduate research). Our new goal is 10 students per academic year in this sequence. As described in the next outcome, we are also adding *number of participants in BEACON-organized cross-disciplinary short courses* to this metric.
- *Number of funding proposals submitted.* Our goal is for 10 multi-disciplinary research proposals to be submitted to outside funding sources per year in the short term and 15 per year in the long term.

L&M Optimal Outcome 2. Increase in cross-institutional research and education. In addition to increasing collaboration across disciplines, BEACON will work to increase collaboration across the five partner institutions. The primary barrier to collaboration is the difficulties inherent

in long-distance communication. The BEACON Center is equipped with videoconference facilities, and BEACON is establishing a culture of collaboration to encourage sharing of Center resources.

Progress towards this outcome will be measured in the following ways:

- *Number of inter-institutional paper/conference submissions.* In the short term, we aim to have 20 submissions/year by BEACON authors from multiple institutions (in the 2012-2013 reporting period, the actual number reported was 16); in the long term we anticipate at least 100 accepted peer-reviewed publications (over the five years) by October 2015.
- *Number of inter-institutional courses.* Three courses were introduced in the first year. Our original long-term goal was to offer an average of one additional course to be offered every other year. However, inter-institutional courses present a large range of logistical problems (especially since some of BEACON's partners are on the semester system while others are on the quarter system). BEACON received two NSF funding supplements for "Materials and Workshops for Cyberinfrastructure Education in Biology" (PI: Titus Brown). This funding has allowed Brown to partner with SESYNC, NESCent and others to offer intensive cross-disciplinary short courses not only at BEACON institutions, but around the world. We believe that these courses are meeting some of BEACON's most fundamental goals, and will do so more effectively over the long term than continually introducing new courses aimed at our BEACON students. Therefore, we are revising this goal to include offerings of cross-disciplinary short courses outside MSU organized or co-organized by BEACON faculty.
- *Number of students in BEACON's cross-institutional, cross-disciplinary courses.* The original goal was 20 students per academic year in the short term, and a cumulative total of 100 across 5 years. As with the above goal, we are revising this goal to more closely match the numbers of new students enrolling each year, and to account for the fact that an increasing number of new graduate students already have an interdisciplinary background in biology and computer science (e.g., students who were involved in BEACON undergraduate research). Our new goal is 10 students per academic year in these courses, and a total of 100 students per year in the cross-disciplinary short courses organized by BEACON faculty.

L&M Optimal Outcome 3. Increase in new funding sources (cross-disciplinary and cross-institutional). BEACON research funds are intended as seed money to stimulate new thinking, encourage new interdisciplinary and inter-institutional research, and to generate pilot data for new proposals for external funding.

We will measure this outcome through *number of submissions*, with a goal of 20 proposals submitted per year, and *award dollars*, with a short-term target of \$5 million per year and a long-term target of \$8 million per year. The primary barrier to achieving this outcome is the *pre-existing* lack of communication across disciplines. One consequence of this barrier is that researchers are not aware of funding opportunities across disciplines. The BEACON Managing Director began guiding the development of tools and information to inform BEACON participants of opportunities across disciplines in August 2010. Additionally, sessions are held at BEACON congresses to allow participants to brainstorm around research problems caused by a lack of communication; congresses have been held every summer since 2010 and have resulted

in many new collaborations and projects. We will also *solicit feedback from the External Advisory Committee* to get an objective assessment of our progress towards this goal.

L&M Optimal Outcome 4. Increase in new participants. We expect that BEACON will attract new participants, and will continue to use that increase as a measure of success. To that end, we will track *the number of faculty* (goal: 50% increase by October 2015), *post-docs* (goal: 100% increase), and *students* (goal: 50% increase in students involved in research). Individuals who transition from one BEACON institution to another (for example, grad student becomes a postdoc at a different BEACON partner) will be counted as new personnel at the destination institution. To attract stellar new participants, BEACON implemented the Distinguished Postdoctoral Scholars program in winter 2011/2012, a competitive fellowship that brings in one new interdisciplinary postdoc a year, for a two-year fellowship. BEACON also developed a Faculty Affiliate Program to attract diverse faculty at other institutions, appointing one new Faculty Affiliate per year with an initial two-year grant of \$100,000. This program has resulted in appointment of two outstanding faculty members to date, and the first of these has already begun contributing substantially to BEACON's scholarly achievements. BEACON now has a Student/Postdoc group to address student concerns, give students representation on BEACON committees, create a sense of community and attract and retain students. Finally, the Managing Director continually updates the website with press releases, blog posts, and announcements about ongoing research and opportunities.

However, BEACON's growth in membership has already exceeded initial expectations, and if both participants (at least 160 hours per year) and affiliates (less than 160 hours per year) are considered, then all three of the above numerical increase goals for 2015 were already met in 2012. While a large membership is desirable, it also represents a dilution in available resources per participant, which has a negative impact beyond some point. Therefore, while BEACON will not close off additional membership, it will no longer have specific numerical targets for numbers of new participants, targeting instead recruitment of the most outstanding and diverse participants.

L&M Optimal Outcome 5. Effective support of Center operations by Management team. To determine whether Center participants feel the Management Team is effectively supporting Center operations, Drs. Patricia Farrell and Marilyn Amey conducted the second formative organizational evaluation throughout 2012, and a more in-depth evaluation in 2013, which generated many concrete recommendations for improvement, many of which the management team had already identified. Plans are underway for ongoing evaluation to ensure progress.

L&M Optimal Outcome 6. Center is perceived by NSF as exemplary. BEACON has the potential to become an exemplary STC. This outcome will be measured in two ways. Our first goal is to receive *renewal of NSF funding*; in the short term we will aim for approval of annual continuation and to receive positive feedback on our annual reports, while our long-term goal is renewal of the grant in 2015. Secondly, we will track *the number of public mentions made by NSF* about BEACON. Our goal is two significant mentions per year, which has been easily met each year so far. The Director will take the lead in ensuring that NSF is continually kept informed of significant BEACON accomplishments.

KNOWLEDGE TRANSFER PLAN

Industry has made extensive use of biologically-inspired computing tools, including artificial neural nets, genetic algorithms, genetic programming, agent-based modeling, differential evolution, swarm computing and artificial immune systems. Sample areas of application of evolutionary tools include data mining and symbolic regression, control of dynamic systems, combinatorial optimization for 2- and 3-D layout, plant floor scheduling, vehicle routing, and single- and multi-objective optimization for product design. BEACON's **Knowledge Transfer goal** is to develop effective mechanisms and pathways to facilitate intellectual exchanges among BEACON partners and industry that will support the sharing of knowledge and application of new technology. While BEACON's initial knowledge transfer plan envisioned establishing a membership-type Industrial Affiliates Program, the experience of the first three years of BEACON operation has revealed that:

- 1) Several companies are interested in sponsoring BEACON projects to explore or demonstrate the applicability of BEACON technologies to their real-world problems, and some have already begun to do so,
- 2) None of these companies is interested in joining a consortial program such as an Industrial Affiliates Program. Instead, each is free to arrange the type of relationship (contractual or otherwise) that suits their purposes and is acceptable to BEACON (generally through one of its member universities).
- 3) Some companies do not wish to publicize their involvement in a particular area of research as they view it as information that is of use to their competitors. They may be willing to provide challenge problems and either proprietary or "sanitized" data to BEACON researchers, but may not want to be joint authors on publications using that information.
- 4) Similarly, some companies may wish to make use of BEACON-developed tools, but not to acknowledge that use to their competitors. Therefore, BEACON must use evidence such as willingness to continue participating in joint research with BEACON as evidence of the benefit being obtained by industry, and to use more generic measures such as number of downloads as evidence of the general usefulness of the tools created by BEACON.

Therefore, BEACON has revised the Knowledge Transfer Plan for 2013 and beyond to eliminate the Industrial Affiliates Program and to focus instead on relationships with individual companies or other organizations, reformulating measures to take into account the lessons above.

Although BEACON has already generated a generic Intellectual Property agreement designed to govern the operation of an industry/university consortium, at this point, such a generic agreement is not actively being used. Of course, BEACON's existing agreement governing treatment of Intellectual Property among BEACON's member universities remains in place. BEACON's Industrial Affiliates Manager shall be retitled to become its Manager of Industry Relations.

KT Optimal Outcome 1. Establishing collaborative research relationships with industrial sponsors. Reaching an agreement on contracts and grants involving research sponsorship and development of intellectual property can be challenging, but some BEACON participants have had previous success in this area, and can work to overcome a given company's inhibitions

concerning collaborating with universities by advising Center participants who are considering collaborations with industry.

We will track our progress towards this outcome through three measures:

- a) the *number of external industry/government laboratory collaborations with BEACON through its member universities*. The goal will be to add one significant industrial collaboration per year in years 4 and beyond,
- b) the *number of joint grant proposals submitted with industrial partners*. The goal will be to submit at least one per year,
- c) the *number of publications submitted that arise from industry-provided challenge problems and data* (per Optimal Outcome 2 below) or are submitted jointly with industrial partners. The goal will be to submit at least two per year. (Note: some companies do not want to make public their interest in a particular topic, so are willing to provide problems and data, but do not wish to be shown as co-authors.)

KT Optimal Outcome 2. Industry-provided challenge problems (i.e. “Real World” problems) and data with feedback.

Instead of working with “toy problems,” BEACON aims to work on real problems with real data provided by industry. In early stages of a relationship with a company, rather than working with proprietary data, we will ask that the company provide “sanitized” data that will allow us to provide a real solution to a real problem, without requiring the company to disclose any proprietary information. We will measure our progress by the *number of instances that challenge problems, data, and feedback are received from industry partners*. Our goal was to receive two challenge problems from industry by October 2011 (this goal was met), a total of at least five by October 2013, and two per year in following years. (These goals have been met through 2013, including, at MSU, 5 challenge problems from automotive, one from the Air Force/BAE, and an autonomous vehicle challenge from Northrup Grummon. Partner University of Idaho has received one in traffic/disaster management.) BEACON’s Manager of Industry Relations will help overcome potential industry partners’ skepticism about the benefits of providing such challenge problems by showing demonstrable results from prior collaborations as part of ongoing communication with industry. However, this numerical goal shall be reduced by one for each instance of a signed contract or grant under KT Optimal Outcome 1 above, because more rapid progress on that outcome supplants the need for instances of Optimal Outcome 2.

KT Optimal Outcome 3. Dissemination and use of BEACON tools and data. We will measure the *number of downloads* of BEACON tools/data (relative to baseline, with the target of a 10% increase in downloads by October 2011 and a 25% increase by October 2013), the number of citations (5% increase by October 2011, 10% increase by October 2013), number and amount of monetary gifts and contracts from industry (target of at least one monetary gift/contract by October 2011, and three by October 2013), and the number of internships and sponsoring companies (increase to at least three by October 2013). All of these goals have been met, as documented in the Annual Report. Work must continue on adding new tools to the set being distributed, and particularly, on their documentation for ease of use by others. The new audio/visual material describing BEACON for visitors, potential partners, was created in 2013 and is now available on the web. BEACON’s Data Management Plan has now been formulated, and BEACON tools are being released and documented in accordance with that plan. Mature

tools of broad interest are intensively documented, while those released simply to document published work receive less effort.

KT Optimal Outcome 4. Spinoffs formed. Another optimal outcome of successful knowledge transfer to industry will be the formation of companies based on BEACON work (e.g., Red Cedar Technology, co-founded by Director Erik Goodman). Our measurement of success will be the *number of spinoffs formed*. The target is to form the initial spinoff(s) within the first 10 years of the Center's existence. Deciding when IP is suitable for commercialization and knowing how to get started are the main barriers to this goal, and BEACON can point people to appropriate resources (e.g., incubator offices) and organize seminars as part of the BEACON Congress meetings. The initial session designed to make BEACON members aware of how to collaborate with industry was organized in summer 2013 by the Manager of Industry Relations, as a sandbox session at the BEACON Congress. Several BEACON members described their industrial relationships, how they were initiated, and advised attendees on pitfalls and approaches to avoiding them.

INTEGRATIVE RESEARCH PLAN

BEACON's **Integrative Research Goal** is to produce transformative, synergistic research through an inclusive collaborative culture that crosses disciplinary and institutional boundaries and is embedded throughout the Center's activities.

IR Optimal Outcome 1. New research collaborations and proposals. We track the *number of interdisciplinary/multi-institutional research projects and publications*: by October 2012, each institution should have at least one new multi-institutional and maybe interdisciplinary collaboration; all institutions will have at least two publications in press and one submitted external proposal by October 2012; these goals were met. We had also planned to track *service by faculty on doctoral research committees across disciplines and institutions*, with the goal of at least one multidisciplinary doctoral research committee associated with BEACON. We are aware of several such interdisciplinary doctoral research committees, including: Erik Goodman (Engineering) and Julius Jackson (Biology) advising Gowon Patterson; Charles Ofria, Chris Adami, Richard Lenski, Ben Kerr, and Eric Klavins also all serve on BEACON-associated doctoral committees outside their disciplines. However, service on doctoral committees is not in publicly accessible records, making this metric very difficult for BEACON management to track. Therefore, we are removing this metric from our strategic plan, as we have ample evidence that continuing to fund interdisciplinary projects that support graduate students will continue to ensure that this sort of multidisciplinary collaboration is ongoing.

Building and coordinating research across geographically dispersed teams can be quite difficult. The Thrust Group and Cross-Cutting Theme Leaders will work continually to ensure more face-time and fewer emails among participants, to allocate travel funds for building relationships among participants, and to coordinate seminars between partners. Engaging graduate students and post-docs in interdisciplinary research can also be challenging, as these trainees tend to be closely connected with a single lab and unaware of training opportunities outside of their advisers' disciplines. BEACON students and post-docs will be required and encouraged to spend time acquiring skills in laboratories outside their disciplines. Faculty advisors in BEACON will play key roles in assisting these participants in finding opportunities.

An important tool in facilitating integrative research will be the Toolbox workshops, developed originally at the University of Idaho (<http://www.cals.uidaho.edu/toolbox/>). These workshops encourage researchers to communicate about the philosophical basis of scientific research, help collaborators identify and examine research assumptions, and are ultimately designed to increase mutual understanding in interdisciplinary research. The Toolbox team ran pilot workshops at the first BEACON Congress in August 2010. The PI and principal developer of the ToolBox instruments, Prof. Michael O'Rourke, moved from University of Idaho to Michigan State University, in Fall 2012, and has partnered with Robert T. Pennock, a BEACON co-PI, to revise the initial workshops. A new version has emerged, focusing on Scientific Virtues for Responsible Conduct of Research Training. Pilot ToolBox/Scientific Virtues workshops were offered at BEACON Friday seminars in Spring 2013 and at the BEACON Congress in August 2013. Additional workshops will be offered in the 2013-2014 academic year and beyond.

IR Optimal Outcome 2. New paradigms for research in organic and digital domains.

BEACON is pioneering the study of evolution in action using a model that joins biological evolution, digital evolution, and evolutionary applications, to their mutual benefit. In contrast, traditional “disciplinary” scientific meetings typically feature one of these areas, but not the others. BEACON will seek to organize meetings or new sessions that expose each of these audiences to the relevant work of the others.

We will measure our progress by tracking *the number of new sessions at scientific meetings or scientific meetings hosted at BEACON* (BEACON participants will submit proposals to scientific societies for workshops or symposia or to organize conferences related to Evolution in Action by October 2013), *the number of new journals and societies*, and *new or increased funding for biocomputational research*. We will also solicit *feedback from the External Advisory Committee* to get an objective assessment of our progress towards this goal.

In service of this outcome, BEACON, in 2012 and again in 2013, requested and received supplemental funding from NSF to organize workshops at BEACON and to coordinate their offering at multiple other NSF STC and Synthesis centers, under the leadership of BEACONite C. Titus Brown. These workshops train biologists in a variety of computational tools useful for study of genomics and evolution. Each of these workshops has been oversubscribed—that is, more people applied than could be accommodated. To encourage other BEACON participants to spend time developing symposia for scientific meetings, short courses, etc., the Management Team and other BEACON faculty will ensure that assistance and support is provided by BEACON administration and by colleagues with shared or complementary interests. In order to try to increase multi-disciplinary and multi-institutional publications; the Education Director and faculty participants will work to change the training expectations of grad students and post-docs to include new biocomputational curricula and rotations in laboratories outside their own disciplines.

IR Optimal Outcome 3. Increase in publications related to evolution in action. We will track the *number of BEACON faculty participants publishing papers*, and *the number of citations of papers that cite BEACON as an affiliation or funding source*. Our aim is for the *number of publications* by BEACON members to have increased over the baseline set in the first year of operation by 10% by October 2013 and 30% by October 2015. We will also measure *the number of links to BEACON*. In addition, by October 2013, at least one new multi-institutional/interdisciplinary result should be covered in a high-visibility outlet such as the New York Times or the Discovery Channel.

Currently, the public media has a resistance to covering evolutionary topics. The Managing Director and the Education Director will work to emphasize the utility of studying evolution in action by facilitating communication with the public. Specifically, the Managing Director has developed a blog on the BEACON website featuring posts by students and postdocs describing their research in an accessible way, and has also used social media (Facebook, Twitter) to publicize BEACON work. The Managing Director also assists BEACON faculty with producing press releases and works with the University Relations office to distribute the press releases and attract publicity. The Education Director will coordinate with NESCent to help increase visibility for the Center. We are also working to put together a brochure for the media, and in the future will also host media and demonstration days. This will be an ongoing goal.

To increase the coverage of biocomputation in the media, the Director, Managing Director, and Education Director will identify key individuals and venues through which to pitch biocomputational evolution in the popular science media. “Informed” science journalists may be invited to BEACON congresses.

IR Optimal Outcome 4. Development and dissemination of new curricula and resources to train multidisciplinary scientists in evolutionary biology and computational evolution. As part of BEACON’s mission, we will develop new materials for training multidisciplinary scientists, including upgrading Avida and Avida-ED. We will distribute these materials within and beyond BEACON.

To measure our progress, we will track the *number of requests for information*. Our target was for downloads of Avida/Avida-ED to increase over the baseline set in the first year by 30% by October 2013, a goal that has been met. During 2010-2011, BEACON developed a research-based course and modules. By October 2012, internal dissemination among BEACON partners was achieved. From then until October 2015, the focus will be on external dissemination, and we will continue to track downloads.

ETHICS PLAN

BEACON's **Ethics Goal** is to practice and promote ethical and responsible research by implementing cross-disciplinary and multi-institutional ethics programs that will inform and guide all participants of the Center.

Ethics Optimal Outcome 1. Center participants will understand shared and discipline-specific practices of Responsible Conduct of Research (RCR). The Graduate School at MSU currently uses a combination of online training and face-to-face mentoring through CAFFE (Center for Academic and Future Faculty Excellence). All partner universities have their own RCR training programs in compliance with NSF requirements. BEACON will track the *percent completion of department- and university-specific RCR training requirements by participants*. Our goal is for 75% of participants to receive the required training by August 2011 (this goal was met), and 100% of participants of more than one year to complete training requirements by December 2012. We will also track the resulting *change in frequency of ethics violations*. Year 2: Ethics violations will be less than 50% of baseline incidence; Year 3: Ethics violations will be less than 10% of baseline incidence. As of October 2013, zero ethics violations by BEACON members have been reported.

We anticipate difficulties ensuring compliance with RCR training, as students and researchers may find the training requirements burdensome. The Managing Director will be responsible for implementing the following policies: BEACON will withhold any renewal/continuation funds until all team members of the applying team have completed RCR training; and new project staff must document completion of RCR training within three months of joining the project. These policies are now in place. The Managing Director will also be responsible for tracking documentation of RCR compliance.

Ethics Optimal Outcome 2. Center participants will embody general scientific norms/virtues, including objectivity, integrity, community, and transparency. We will measure *baseline and follow-up participation in a Scientific Virtues workshop*. In 2013, Dr. Pennock gave a series of presentations on the scientific virtues and their relationship to RCR at the regular BEACON group meetings. These also served as a pilot test of the virtues-based approach to RCR training that he is developing. Dr. Pennock and the Toolbox project are now developing new modules for the Toolbox that focuses on these ethical norms and expectations, and offered the first 4 workshops at the 2013 BEACON Congress.

Faculty, students, and post-docs gather at a weekly BEACON meeting to discuss research progress and to have a social hour, every Friday at BEACON headquarters. Graduate students, postdocs, and faculty members from all BEACON institutions give 30- or 60-minute presentations on their work. While participants in BEACON-funded projects are required to give at least one presentation per funded year, all BEACON members are encouraged to present their BEACON-related work whether funded or not. We also regularly host visiting speakers from other institutions that present research of interest to BEACONites. Students and faculty at partner institutions participate in the research discussions by videoconference and are encouraged to replicate the social hour at their own institutions. Such activity encourages the development of a BEACON community.

Ethics Optimal Outcome 3. Respect for views and ideas “horizontally” and “vertically.”

BEACON will encourage collaboration and respect for ideas both “vertically” (that is, between people of different ranks) and “horizontally” (that is, across disciplines). This outcome will be measured by the *number of Toolbox seminars and trials* and by the *number of BEACON participants who get cross-disciplinary training*. In August 2010, the Leadership and EHRD teams participated in the Toolbox Workshop. Pilot workshops were conducted for three multidisciplinary research teams at the BEACON Congress in August 2010. A funding gap and conflicting commitments experienced by the Toolbox team precluded their participation in many BEACON activities during 2011 and spring of 2012. However, in 2013, Michael O'Rourke teamed with Dr. Pennock to develop new Scientific Virtues Toolbox modules, and offered the first 4 workshops at the 2013 BEACON Congress. By October 2014, our goal is for greater than 50% of BEACON participants to have participated in one of these sessions.

Ethics Optimal Outcome 4. Participants have access to shared resources and mechanisms to negotiate intellectual/philosophical differences. We will measure *the fraction of participants that are aware* of resources for such negotiation, using a survey. By October 2014 we aim to achieve 50% awareness of resources through Toolbox and local BEACON training. By October 2015, our aim is to increase that awareness to 75%.

RESEARCH OUTPUT GOAL

BEACON's **research output goal** is to disseminate widely an increasing quantity of original and highly regarded scientific research on evolution in action.

Research Output Optimal Outcome 1. Original research by BEACON members on evolution in action will be prominent in the evolution literature. Our progress towards this goal will be measured by *the number of publications in peer-reviewed journals, presentations at scientific conferences, and grant proposals submitted*. Our goal in the short term is 150 publications, 150 conference presentations, and 40 grant proposals submitted per year in the first two years. These numbers were met in 2012 and 2013, but not 2011 – likely due to underreporting by BEACON members. Our original goal was to increase these numbers by 50% by October 2015, but we are considering revising this goal due to difficulty in reliably tracking this information.

Research Output Optimal Outcome 2. BEACON research output will be perceived as making an important contribution to the literature. We will measure our progress towards this goal by soliciting *feedback from the External Advisory Committee*, who will provide an objective view of our progress.