Annual Report on Investments in Training and Education for the NIH Big Data to Knowledge (BD2K) Initiative

Report on investments during FY14-16

Prepared by the BD2K Training Program Management Working Group

March 2017
Executive Summary

Training is a major limiting factor to extracting knowledge from data, and therefore it is a significant part of the Big Data to Knowledge (BD2K) Initiative. One of the primary aims of the BD2K Initiative is to enhance training in the development and use of methods and tools necessary for biomedical Big Data science. To accomplish this aim a number of training and education opportunities have been developed that are designed to increase the number of biomedical data scientists and to improve the data science skills of all biomedical scientists.

Because training needs vary greatly based on an individual’s prior background and intended use for data science, the BD2K investments in training are also varied. For those individuals who are primarily biomedical scientists and do not intend to become specialists in data science, BD2K supports courses and educational resources that are meant to enable participants to become conversant in data science and attain skills to utilize data science methods. To support those individuals who wish to become specialists in biomedical data science, BD2K includes training programs for predoctoral students, research rotations for early career scientists, and career development awards for postdocs and more senior researchers. To foster the development of new teams consisting of biomedical scientists and data scientists, BD2K is supporting the QuBBBD (Quantitative Approaches to Biomedical Big Data) Program along with the National Science Foundation.

Among the first BD2K awards issued (in September 2014) were research education awards and mentored career development awards, and they are starting to bear fruit. For example, the first BD2K Open Educational Resources, in the form of Massive Open Online Courses, have been released and already boast thousands of graduates; three summer courses were offered and filled to beyond capacity; and individuals supported by career development awards have transitioned to independent research positions. Although the existing awards made in FY14-16 are promising, additional investments are needed to keep up with the fast-changing area of data science.

In order for BD2K-supported resources to have maximal impact, they need to be findable, accessible, interoperable, and reusable (FAIR). To help biomedical scientists find and access data science educational resources, the BD2K Training Coordination Center (TCC) has developed an Educational Resource Discovery Index. To enhance this resource the TCC is working with international partners such as ELIXR that provides an online training portal that gathers life science training materials and training courses from across Europe, and allows you to search it in one website. Through the TCC and the other training awards, BD2K aims to improve the ability of the entire biomedical science community, whether specialists in biomedical science or in data science, to utilize the growing volume and complexity of data.
**Overall Goals**

Focusing on training was one of the main recommendations from the Data and Informatics Working Group Report to the Advisory Committee to the Director (link to June 2012 report [here](#)). It is also one of the major thrust areas of the BD2K Initiative and the NIH Office of the Associate Director for Data Science. Training currently accounts for approximately 15% of the budget for the BD2K Initiative with FY16 expenditures of nearly $17 million for new and continuing awards. The term “Training” is meant to encompass training, education, and workforce development that provides learners, no matter what career level, either foundational knowledge or skills for immediate use.

The two main goals for BD2K training are to improve big data skills in biomedical scientists and to increase the number of people who specialize in biomedical data science. These two goals include sub-goals as well:

1) **To improve big data skills of biomedical scientists**
   - A. Support training opportunities, both in-person and online
   - B. Ensure training opportunities and resources are more readily discovered and accessed
   - C. Enhance diversity in the biomedical and biomedical data science workforces

2) **To increase the number of biomedical data scientists**
   - A. Establish biomedical data science as a career path
   - B. Foster collaborations between biomedical scientists and data scientists

To accomplish these goals, the currently supported training portfolio is diverse. Funding opportunities were issued (see Appendix A) that were designed to be responsive to the two goals:

**Goal 1: To improve the big data skills of biomedical scientists:**

- Goal 1A: Research Education Grants (R25) to support the development of courses and resources in data science, data management and data sharing, annotating and curation (4 funding opportunities were issued to allow for different budgetary categories and structures)
- Goal 1B: Training Coordination Center (TCC) (U24)
- Goal 1C: Research Education Grants (R25) to enhance diversity (denoted dR25 to distinguish it from the other R25s)

**Goal 2: To increase the number of biomedical data scientists:**
Goal 2A: Mentored Career Development Award (K01) and Predoctoral Training Award Programs (T32 and T15) (3 funding opportunities to support both new programs and supplements to existing T32s and T15s)

Goal 2B: Training Coordination Center (U24) to provide support for innovative approaches to fostering collaborations (Note: BD2K also supports the QuBBD (Quantitative Approaches to Biomedical Big Data) Program in collaboration with the National Science Foundation)

Figure 1: Existing Awards Map onto One or More BD2K Training Sub-Goals.

BD2K Training Sub-Goals:  
1A: Support training opportunities, both in-person and online
1B: Ensure training opportunities and resources are more readily discovered and accessed
1C: Enhance diversity in the biomedical data science workforce
2A: Establish biomedical data science as a career path
2B: Foster collaborations between biomedical scientists and data scientists

Existing Awards:
R25
Diversity R25
T32/T15
K01
U24

The first set of funding opportunities were issued in FY14 and FY15. During FY16, a portfolio analysis was conducted and based on a continued need and identified gaps in the portfolio several funding opportunities were issued. These include opportunities that were reissued for support for predoctoral training grants (T32), mentored career development awards (K01), open educational resources for skills development (R25), and research education grants to enhance diversity and build capacity at under resourced institutions (dR25). Two new opportunities were also released to support the transition of intramural investigators to independent research careers in the extramural community (K22) and to support the creation or significant expansion of courses in Data Science targeting undergraduate and/or graduate students with the objective of enabling institutions to easily incorporate tailored data science skills into their standard curriculum for biomedical scientists (R25) (see Appendix A). At the time of this report there are no results to report on from the reissued or new opportunities.

Figure 2: Number of Awards by Goal. A total of 70 grants or awards were issued by BD2K in response to the two goals (Appendix B). There are 33 awards providing support
to improve the big data skills of all biomedical scientists (Goal 1) and 37 awards providing support to increase the number of biomedical data scientists (Goal 2). For the purposes of this report, the Training Coordination Center Award was assigned to Goal 1. During FY16 several administrative supplements were issued to supplement and enhance the activities of some of the awards that are not accounted for in Figure 2 but are listed in Appendix B.

**Figure 3: Percent of Budget by Goal.** During FY16 the training component of the BD2K Initiative expended 59% of the training budget on Goal 1 and 41% of the training budget on Goal 2.
In addition, each of the BD2K Centers of Excellence has training components. Because the Centers’ training is diverse and mainly focused on training about specific tools developed by the Centers, they are not included in this report.

Collectively, BD2K training reaches an audience of varying experience levels and intentions, from undergraduates to senior faculty and instructors who will be teaching data science. Some of the awards are targeted at particular career levels. For example, the R25 awards to enhance diversity are for undergraduates, the T32/T15 programs are for predoctoral trainees, and the K01 awards are for postdoctoral fellows and beyond. Other awards, such as the U24 TCC and the R25s can accommodate a broad range of experience levels.

**Figure 4: Number of Awards by Grant Mechanism (FY16).** From FY14-16 a total of 70 awards have been issued in the area of training and education for the BD2K Initiative. Figure 4 displays the number of awards issued for each grant mechanism. They are: dR25: Research Education Grant to support activities to diversifying the workforce and building capacity at under resourced institutions; R25: Research Education Grants to support the development of courses and resources; T32/T15: Training Grants to support the development of predoctoral training programs; K01: Mentored Career Development Award to support mentored career development; U24: Cooperative Agreement to support the development of the BD2K Training Coordination Center.
Figure 5: Awards as a percentage of total budget dedicated to training and education for the BD2K Initiative during FY16.

Figure 6: Total Expenditure to Date for BD2K Training Efforts in millions of dollars. The expenditures include new and continuing award costs.

Because BD2K is a trans-NIH program, with funds coming from all NIH Institutes and Centers (ICs) and the NIH Common Fund, IC input has been actively solicited. The
funding opportunity announcements (FOAs) were developed by a trans-NIH group of program directors, first called the “BD2K Training Subcommittee” and later referred to as the “BD2K Training Program Management Group”. This group has welcomed all-comers, from all ICs and Offices within the NIH Office of the Director, with effort to recruit members through two presentations to the NIH Training Advisory Committee. All programmatic aspects, including FOA development, review attendance, pay plan development, and decisions about award management, have been done through the trans-NIH group that includes 13 ICs, the Common Fund, and the Office of Behavioral and Social Science Research (see Appendix G). Day-to-day management of the awards is distributed across 5 ICs to include as many ICs as possible and to ensure that grantees are treated uniformly.

**Figure 7: Number and Distribution of Awards by Managing IC.** Note that during FY16 one-year administrative supplements were issued to the NIH Science Education Partnership Award (SEPA) Program that is managed by the NIH OD in the Office of Research Infrastructure Programs (ORIP). The purpose of these supplements was to incorporate data science into curriculum that is aimed to increase student interest in pursuing biomedical research careers and increase understanding of the scientific research progress and/or hold professional development courses for K-12 teachers that would enhance their knowledge of data science. The budgets of these awards are accounted for in previous figures using the R25 grant mechanism but were not counted as individual awards per se as they are supplements to grants that did not originate from the BD2K Initiative.
**Goal 1: To Improve Big Data Skills of Biomedical Scientists**

To improve the big data skills of biomedical scientists, the BD2K Initiative provides support for the development of training opportunities, both in-person and online; ensures training opportunities and resources are more readily discovered and accessed; and provides support to enhance diversity in the biomedical and biomedical data science workforces.

**Goal 1A: Support training opportunities, both in-person and online**

The BD2K open educational resources and short courses aim to introduce biomedical scientists to data management and data science. These programs were designed to be flexible, to allow for innovation and for specialization to a particular audience, domain science, or data science. Although a few of the funded programs are confined to a narrow audience or scientific area, most are for general audiences and multiple data types. During FY14-FY16, a total of 32 R25 programs were funded, and these programs have a broad reach geographically. More detail about the audience, scientific breadth, and reach follows.
Audience:

The R25 awards address a variety of educational levels (undergrads to senior faculty) and intended usages (end users or instructors).

- Five programs focus on helping instructors of advanced undergrad/early grad courses. Examples include:
  - A train-the-trainers course in biomedical data science for instructors, who will collectively develop a curriculum for undergraduates at non-research-intensive colleges
  - Curricular materials (slides, assessments, reading suggestions) that can be used and adapted by other instructors
  - A Toolkit to help librarians teach data management to biomedical scientists
- Seven programs target undergrads directly, through summer programs (including didactic and research experiences) that aim to recruit data science students into biomedical science or to expose biomedical students to data management and data science. Four of the seven programs have a primary goal of enhancing diversity through partnering with BD2K Centers.
- The remaining 16 programs focus directly on the graduate student or the more advanced learner; although the data management and data science material is introductory, because it is new, learners are just as likely to be senior faculty as graduate students.

Figure 9: Number of R25 Awards by Type of Audience
Scientific Breadth:

Although the majority of the programs aim for a general biomedical audience, some of them focus on a particular data type. Over a quarter of the programs focus on genomics, and approximately another quarter focus on one of imaging, clinical, or population data. Several courses or resources utilize multiple types of data types, one course is focused on utilization of neuronal data sets and several other courses and resources have an emphasis on the technical aspects of data science and do not focus specifically on a particular type of data.

Figure 10: Courses and Resources by Scientific Domain or Focus

Areas with few applications and hence few funded applications are the clinical and population sciences. Within these areas, this is notable dearth of activity in mHealth. This was noted in the reissuance of the R25 for open education resources (reissued in FY16). The new FOA included language encouraging applications that would educate participants on using, analyzing and/or integrating clinical or mobile health data among other topics. BD2K continues to work closely with relevant Institutes, Centers and Offices, such as NCATS and OBSSR, to ensure that new funding opportunity announcements contain language to encourage applications in all domain areas relevant to biomedical, behavioral, clinical, and social science research focused on health and that new opportunities are widely advertised to the appropriate communities.
• Data Management and Data Science: Collectively, the awards span a broad range of topics, including data management, data exploration, data representation, computing, data modeling, and data visualization. Each of these topics can be further broken down in the following way:
  • Data management: reuse of data, data standards, locating and accessing data and tools, organizing and curating data through ontologies and use of metadata
  • Computing: distributed or parallel computing, workflows, programming, algorithms, optimization, and natural language processing
  • Data representation: data structures and databases
  • Data exploration: data munging and preparation, exploratory data analysis
  • Data Modeling: probability, stochastic modeling, introductory statistics, advanced statistics (e.g. multiple testing, dimension reduction), machine learning, experimental design, Bayesian methods, reproducible research, network models
  • Data visualization and communication

Although collectively the R25 awards span the range above, they are often covered with little depth, and some of the topics are only covered by one Open Educational Resource, and these tend to be the more technical (e.g. optimization and stochastic modeling) or specialized [e.g. ethical, legal and social implications (ELSI) and team science] topics. Appendix C and Appendix D shows which of the topics given above are included in each of the R25 awards.

Reach:

• Eleven programs with in-person components are spread evenly between East coast, West coast, and the middle of the country. Based on the planned enrollments, the 11 programs will serve over 250 participants in the summer of 2016.
• The three programs that were funded in FY14 held courses in the summer of 2015. They collectively reached undergraduates, PhD students, and faculty from over 30 different universities.
• Demand for the 2015 in-person courses was high, with reported acceptance rates for the programs with limited slots as being 35% and 14%. Another program gave support to a limited number of students but opened a large auditorium for the course.
• Fourteen of the awards are online Open Educational Resources. These reach a large number of students and instructors, providing a great value per student.
• For example, about 5,000 students completed the first 8 courses in Rafa Irizarry’s series of biomedical Data Science MOOCs in the first offering,
amounting to about $40 per student based on an NIH investment of $200K (year 1 direct costs).

Although BD2K is supporting the development and discovery of training resources, continued support in the area is needed for a number of reasons: gaps in content coverage exist (e.g. methods for mHealth data, algorithms and optimization methods, advanced statistics, network models); demand for in-person courses continues to exceed supply; different ways of explaining material resonate with different learners; and materials need to be updated to take into account new science and new developments in the understanding of learning.

At the August 2016 meeting of the BD2K Multi-Council Working Group, Council members suggested that BD2K should focus on training and education not only for current scientists but also on future scientists – that is students in elementary, junior and high school. In response to this call, the BD2K training program management group reached out to the NIH Science Education Partnership Award (SEPA) Program. The SEPA Program funds innovative K-12 STEM and Informal Science Education (ISE) educational projects. SEPA projects create partnerships among biomedical and clinical researchers and K-12 teachers and schools, museums and science centers, media experts, and other educational organizations. SEPA K-12 resources target state and national K-12 standards for STEM teaching and learning and are rigorously evaluated for effectiveness. BD2K offered to fund one-year administrative supplements through the SEPA Program to: 1) Incorporate data science into curriculum that is aimed to increase student interest in pursuing biomedical research careers and increase understanding of the scientific research process; and/or 2) Hold professional development courses for K-12 teachers that enhance their knowledge of data science. For an interim report of these programs please see Appendix E.

**Goal 1B: Ensure training opportunities and resources are more readily discovered and accessed**

Training opportunities need to be available, and biomedical scientists need to find and access the ones that best fit their needs. To this end, BD2K supports the development of training opportunities and their dissemination to large numbers of learners, as well as infrastructure for discovering them.

To help biomedical scientists find, access, and choose training opportunities, the Training Coordination Center has created an Educational Resource Discovery Index (ERuDite). ERuDite is a discovery index that organizes pointers to educational content, utilizing metadata describing the educational resource. Utilizing and extending common metadata is being pursued through an international collaboration between the TCC and ELIXIR, a European-based federation of organizations that build infrastructure for the life sciences. Please see link to access ERuDite: here.
ERuDIte, when combined with a knowledge map that shows how Big Data skills relate to one another, may form the basis of a personalized learning system for biomedical scientists to efficiently acquire new skills to tackle Big Data.

To date, ERuDIte contains over 255 videos and educational resources that have been generated through the support of the BD2K Initiative. An additional 10,000 training resources have been collated from open resources collected across the internet including YouTube, Coursera, VideoLectures, Kahn Academy, and ELIXIR. Additional content is uploaded at regular intervals. It is expected that content from the International Neuroinformatics Coordinating Facility (ICNF – link for more information) will be uploaded soon as well as content from the H3Africa Initiative (link for more information).

For an interactive map of all BD2K Training activities with active links to the direct resources (Massive Online Open Content (MOOCS) or other online content), description of the in-person courses, predoctoral training programs and mentored career development awards please see the following sunburst: here.

**Figure 11:** Interactive sunburst clickable image map that can be used to explore awards supported through the BD2K Initiative. Produced by the BD2K Training Coordination Center.
Educational content may also come from other sources that the BD2K Initiative did not support. Some of the BD2K Centers, which each have a training component, are producing educational content such as TED-like talks. Curriculum for data science courses may come from BD2K T32/T15 training programs, which were given the opportunity to apply for $20K in funds to develop and share curriculum of new courses. The number of educational resources supported by BD2K, or even NIH, is dwarfed by the number supported elsewhere, whether by the National Science Foundation, the Department of Education, foundations, universities, or private industry. Educational resources from all of these sources has been included as content in ERuDIte.

Another opportunity that the TCC has developed is weekly Fundamental in Data Science webinars. This is a virtual lecture series on the data science underlying modern biomedical research. Beginning in September 2016, the webinar series consists of weekly presentations from experts across the country covering the basics of data management, representation, computation, statistical inference, data modeling, and other topics relevant to “big data” in biomedicine. The webinar series provides essential training suitable for individuals at an introductory overview level. All video presentations from the seminar series are streamed for live viewing, recorded, and posted online for future viewing and reference. These videos are also indexed within ERuDIte. This webinar series is a collaboration between the TCC, the NIH Office of the Associate Director for Data Science, and BD2K Centers Coordination Center (BD2KCCC). For more information see here.

**Goal 1C: Enhance diversity in the biomedical and biomedical data science workforces**

The dR25 programs are a main component of BD2K’s diversity efforts. Four undergraduate programs aim to enhance diversity in the biomedical workforce through partnerships between the BD2K Centers of Excellence and low-resourced institutions. The partnerships support the development of curriculum and research experiences for undergraduates and faculty from low-resourced institutions. For example, in partnership with Harvard University and the University of Puerto Rico, Río Piedras (UPR-RP) the students at the UPR-RP take the Massive Online and Open Course (MOOC) developed by Rafael Irizarry from Harvard. This MOOC was one of the first Open Educational Resources funded by the BD2K Initiative. Collectively, these four programs reach 134 students directly over the course of 5 years. However, the number of students touched by the improved curriculum and the strengthened faculty is far greater. For example, with administrative supplement support provided to California State University at Fullerton (PI: AJ McEligot), an introductory video on big data science was developed with the goal of introducing students to big data and how this knowledge can be applied to provide solutions to critical questions in bioscience and health. The video has been incorporated into classroom instruction with most students agreeing or strongly agreeing that they understand better the respective topic being
covered. (Video link: here.) This video, targeted towards undergraduate students in multiple departments has the potential to reach over 400 students per year. In addition, the PIs of these four programs met at the BD2K All Hands Meeting and have worked together to share experiences and resources. An accepted publication in Ethnicity and Disease on Enhancing Diversity in Biomedical Data Science demonstrates these collaborative interactions (Authors: JE Canner, AJ McEligot, M-E Perez, L Qian, X Zhang). This publication suggests that these four programs provide models for what various types of institutions might consider to enhance diversity in biomedical big data science.

In addition to the four programs funded explicitly for diversity, other R25s make serious efforts to recruit and train underrepresented minorities. For example, in the first offering, the short course from Oregon Health Sciences University trained 9 participants that were underrepresented in health-related research out of the 17 total participants. Although the R25 programs form the core of BD2K’s diversity efforts, underrepresented participants in health-related research can be supported by BD2K through the T32/T15 training programs, which must have plans to recruit and retain a diverse pool of students.

Goal 2: To Increase the Number of Biomedical Data Scientists

To increase the number of biomedical data scientists, trainees need to gain the appropriate skills, want to work in biomedical science, and have an appropriate place to work. Because all of these trainees have self-selected toward biomedical science, BD2K’s focus is on helping trainees get the appropriate skills initially and use those skills in the long run. Trainees may be 1) predoctoral students, who gain foundations in biomedical data science through T32/T15 training programs, 2) postdocs/faculty, who are trained in either biomedical science or data science and recognize the need to complement their existing knowledge and skills through K01 career development awards, or 3) students or faculty who need specialized training that is unavailable locally but attainable through a Research Rotation.

Retaining trainees is both important and a challenge, due to the demand for data science skills across sectors. Although retention is being addressed primarily through providing support, BD2K is also interested in facilitating conversations with university leaders to discuss career paths for open science and data science. Support for the further development of data scientists into biomedical data scientists is given through K01 awards. Before blending biomedical and data science knowledge, data scientists may be able to immediately contribute to addressing biomedical problems through working in teams with biomedical scientists. Such teams are being fostered through joint NSF/BD2K support in the QuBBD program, for building collaborations between data scientists and biomedical scientists.
Goal 2A: Establish biomedical data science as a career path

T32/T15 Training Programs:

Predoctoral trainees are supported through new T32 programs and supplements to existing NLM T15 programs: 6 were funded in FY14, and another 10 were funded in FY15. Each training grant could request up to 6 predoctoral training slots per year, however, since many of the departments that the programs reside in are new, not all programs requested the maximum of 6 slots. To date, these training grants have supported 85 unique individuals. Though it is extremely early in the program, out of these 85 individuals, 2 have been successful at acquiring NIH predoctoral fellowship support through the Ruth L. Kirchstein National Research Service Award (NRSA).

To enhance the trainees interactions with each other, BD2K supported trainee networking events at the 2016 American Statistical Association Conference on Statistical Practice (link [here](#)) with approximately 35 students in attendance and at the annual BD2K All Hands Meeting of BD2K-funded investigators with approximately 20 students in attendance.

Because the field is nascent, there is still not full agreement as to what the core competencies are. However, some of the common areas of most BD2K training programs are: modern statistics (e.g. handling multiple comparisons, high dimensional data analysis, spatial-temporal correlation), computational techniques (e.g. using cloud and parallel computing, optimization, and algorithms), and machine learning. Most programs are creating new courses in order to integrate these topics together and focus class time on the ones that need to be learned didactically. Below is a word cloud of the core courses of the programs; a listing of these courses is given in Appendix F.
K01 Career Development:

BD2K is supporting 21 postdocs and faculty with mentored career development awards (K01). The PIs come from diverse backgrounds:

- 9 are physicians, with specialties in hematology/oncology, neurology, neuroradiology, surgery, urologic surgery, pulmonary and critical care medicine, and internal medicine
- 7 have primarily quantitative or computational backgrounds, with degrees in Electrical Engineering and Computer Science, Physics, Nuclear Physics, and Biomedical Engineering
- 3 have backgrounds in fields that blend the biomedical and computational sciences (molecular genetics, bioinformatics and computational biochemistry)
- 2 are behavioral or social scientists (Social Epidemiology, Quantitative Psychology)

Figure 12: Backgrounds of the Funded Mentored Career Development Awardees.

The group of K01 awardees is diverse not just by scientific background but also demographically and geographically:

- Nine out of 21 are female.
- They work at 18 unique institutions.

Through a sustained period of research career development and training, the K01 awardees will gain the knowledge and skills necessary to launch independent research careers. Awardees have at least two mentors, and the mentors were required to be active investigators in at least one of the areas involved in Big Data Science (computer
science or informatics, statistics and mathematics, and biomedical sciences) and their experiences must encompass two of these areas and complement each other. The ultimate goal of this opportunity is to provide support for the awardee to become competitive for new research project grant (e.g., R01) funding in the area of Big Data Science.

To date, the K01 awardees have been extremely productive. Four have moved to different academic institutions for tenure track jobs or promotions. Two have moved from an academic institution into an industrial setting, continuing with their research project but without the support of the K01. Fifteen out of twenty-one (71%) are actively publishing on their projects with an average publication rate of 4 publications per person with a range of 1-11 publications. As of February 2017, two have received R01 funding from the NIH and another three have active R01 applications pending review.

Data Science Rotation for Advancing Discovery – RoAD-Trip Research Rotations

In addition to creating this index of educational resources, the TCC supports fellowship support to junior biomedical scientists wishing to acquire new knowledge and collaborations with more senior-level data scientists. This opportunity is called “Data Science Rotation for Advancing Discovery” (RoAD-Trip). The TCC has developed a match-making process that provides the opportunity for participants to conduct a focused joint project with an initial rotation of at least 2 weeks within a 5 month period where the participant can be immersed within the mentors lab. Most of the trainees are expected to be graduate students, but they could also be postdocs/junior faculty. This opportunity provides up to $4000 for the participant to help defray travel and living expenses and an honorarium to the mentor of $1000. In late 2016, 23 applicant fellows and 16 mentors applied for matching, with 10 applicant fellows and 8 mentors selected. The fellows career levels included masters level, postdoctoral and Assistant Professors with projects related to behavioral, clinical and biological big data questions.

Goal 2B: Foster collaborations between biomedical scientists and data scientists

NSF/NIH Quantitative Biomedical Big Data (QuBBBD) Program:

Some problems will require a new model of leadership. Particularly when very diverse skills need to be brought to bear on the problem, teams of individuals with complementary expertise will be needed. Such teams are being fostered through a partnership between NSF and NIH called the QuBBBD program. This program consists of a series of Innovation Labs and the funding of planning grants.

Innovation Labs are week-long mentored workshops that catalyze interdisciplinary teams and speed up the process of developing the team’s research program. BD2K ran a pilot Innovation Lab in July 2015. By the end of the week, 12 new interdisciplinary
teams were prepared to submit grant applications together. The teams submitted applications for small planning grants, along with newly-formed teams that did not go through the Innovation lab.

Because an established team can do much work virtually, the teams fostered by the QuBBBD program draw in a wide range of talent, many of whom are from schools not otherwise represented within BD2K. These teams include some data scientists who are in physically isolated locations along with biomedical scientists who are unable to find data science collaborators due to the high demand.

The Summer 2015 Innovation Lab was successful. Evidence of this success is that the teams nurtured in the Innovation Lab had a much higher success rate than the other teams. The key to success was the participation of mentors who are from a variety of backgrounds and are leaders in their respective fields. The mentors guide teams through the iterative ideation process, offering feedback on research ideas throughout the week.

During FY16 the theme of the Innovation Lab involved addressing the data science needs arising from the use of wearable or ambient sensors to study health and disease. Thirty-one participants (13 women and 18 men) were invited to the 2016 Innovation Lab focusing on wearables and environmental sensors. The group represented an approximate split in biomedical and quantitative backgrounds (14 biomedical and 17 quantitative). After the week-long workshop to ideate and form new interdisciplinary teams with guidance from the five mentors who participated, 8 new teams formed around 8 new project ideas. During FY17 the theme of the Innovation Lab is on quantitative approaches to biomedical data science challenges in our understanding of the microbiome. Link to more information here.

**Summary**

The BD2K programs in training described in this document are early efforts to respond to and address a need identified by the Advisory Committee to the Director’s Data and Informatics Working Group. They cover both biomedical data science specialists, as well as specialists in other biomedical areas. They also cover the educational pipeline from undergraduates to faculty.

These programs are “early efforts” because there is still much work to be done to meet both goals. To quickly increase the base data science skills of a wide variety of biomedical scientists, early resources focused on broad, generally applicable topics. Later resources might be on more specialized topics. Likewise, to quickly jump start the increase in the number of biomedical data scientists, some of the training programs are modifications of existing programs, building on existing infrastructure and courses. As the community converges on the core competencies of the field, biomedical data
science training programs will likely evolve and may end up bearing little resemblance to the programs initially funded.

The BD2K Initiative is in its infancy, and the training programs, along with other BD2K programs, are contributing to the development of the field of biomedical data science in the US and across the world. Although the awarded grants are confined to US institutions, the reach extends far beyond through the development of open educational resources and contributions to the global conversations about the field of biomedical data science. In addition, international collaborations surrounding the discovery of open educational resources for biomedical data science have begun. The BD2K program aims to improve the ability of the biomedical workforce to use Big Data both today and tomorrow, both in the US and across the world.

**Figure 13: Geographic Distribution of BD2K Training Awards**
### Appendix A: List of Funding Opportunity Announcements for the BD2K Initiative in the area of Training

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<th>FY Released</th>
<th>Title</th>
<th>Number / Hyperlink</th>
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<td>Notice of NIH/BD2K Participation in the Joint NSF/NIH Initiative on Quantitative Approaches to Biomedical Big Data (QuBBD)</td>
<td>NOT-EB-16-008</td>
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<td>FY16</td>
<td>BD2K Research Education Curriculum Development: Data Science Overview for Biomedical Scientists (R25)</td>
<td>RFA-ES-16-011</td>
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<td>FY16</td>
<td>NIH Big Data to Knowledge (BD2K) Enhancing Diversity in Biomedical Data Science (R25)</td>
<td>RFA-MD-16-002</td>
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<td>FY16</td>
<td>BD2K Open Educational Resources for Skills Development in Biomedical Big Data Science (R25)</td>
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<td>FY16</td>
<td>NIH Big Data to Knowledge (BD2K) Mentored Career Development Award in Biomedical Big Data Science for Clinicians and Doctorally Prepared Scientists (K01)</td>
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<td>NIH Big Data to Knowledge (BD2K) Mentored Career Development Award in Biomedical Big Data Science for Intramural Investigators (K22)</td>
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Partnership |
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| 3 | R25 | OD016519-03S1 | HODGES, GEORGIA  
Stimulating Young Scientists To Engage, Motivate and Synthesize (SYSTEMS) |
|   | PAR-10-206 | RePORTER Proj Info |
| 3 | R25 | OD016513-03S1 | IMONDI, RALPH  
(SAINTSCHI, LINDA ANITA)  
NeuroLab M3: Discovery-based explorations of scientific models, model organisms |
|   | PA-14-077 | RePORTER Proj Info |
| 3 | R25 | OD010494-03S1 | MARKOWITZ, DINA GROSSMAN  
Medicines and Me: Understanding and Using Medicines Safely |
|   | PAR-10-206 | RePORTER Proj Info |
| 3 | R25 | OD016511-03S1 | MICKLOS, DAVID ANDREW  
Barcode Long Island: Exploring Biodiversity in a Unique Urban Landscape |
|   | PAR-10-206 | RePORTER Proj Info |
| 3 | R25 | OD016542-03S1 | WOOD, CHARLES ARTHUR  
Pandem-Sim: Saving the World with Biology |
|   | PAR-10-206 | RePORTER Proj Info |
| 3 | R25 | OD016490-03S1 | WYSS, J MICHAEL  
Science Education Enabling Careers (SEEC) |
|   | PAR-10-206 | RePORTER Proj Info |
Appendix C: Topics in BD2K R25 Courses, by PI

Open Educational Resources (OER) – Online:

Amaro (modules)
- biomedical big data
- data access
- data standards / interoperability / ontologies
- workflows
- biostatistics

Caffo (two MOOC series)
- The human brain
- Imaging modalities and data types
- Quantitative neuroanatomy
- Neuroimaging pipelines
- fMRI
- Quantitative clinical neuroimaging
- Introduction to genomic technologies
- Sequence alignment and processing
- Sequence assembly
- Normalization and preprocessing
- Statistical analysis of genomic data

Hersh (curricular materials)
- Biomedical, Clinical, and Translational Research data life cycle
- Introduction to Big Data
- Ethical Issues
- Terminology
- Computing Concepts
- Clinical Data and Standards
- Basic Research Data Standards
- Public Health and Big Data
- Team Science
- Secondary Use (Reuse) of clinical data
- Limitations of Reuse of Clinical Data
- Information Retrieval
- Version control and identifiers
- Data annotation and curation
- Data and tools
- Ontologies 101
- Data modeling
- Data metadata and provenance
- Semantic data interoperability
- Semantic Web data
- Context-based selection of data
- Translating the Question
- Implications of Provenance
- Data tells a story
- Algorithms
- Basic statistics
- Visualization
- Reproducibility

Irizarry (MOOC series)
- Basic programming
- Python
- R
- Software engineering
- Inference
- Models
- Clustering and prediction
- Smoothing
- Algorithms
- Data Structures
- Large data
- Optimization
- Visualization
- Networks
- Communication

Lee
- N/A; this is a resource not an online course
Pevzner (MOOC)
- Algorithms
- Statistics
- Machine learning
- Data analysis

Bohland (15 MOOC modules)
- Introduction to MATLAB
- File and code management, metadata, web services / APIs, database systems, parallel computing approaches
- Visualization
- basic statistics
- Spectral analysis
- Cross-frequency coupling
- Dimensionality reduction
- point processes
- generalized linear modeling
- Interspike interval distributions
- Field-field coherence and spike-field coherence
- state-space modeling
- false discovery rate
- Linear discriminant analysis, support vector machines, cross-validation
- filtering
- network construction, correlation, partial correlation, network measures
- Heat maps, hierarchical clustering, multidimensional scaling, spectral graph partitioning, Mantel test

Elgin
- N/A; this is a resource, not an online course

Churchill (curricular materials)
- Data analysis
- Statistics
- Modeling

Courses – in person:

Dorr (4 days, undergrad)
- Overview of big data and its uses; teamwork in big data science
- Data types, formats, and definitions in research
- Finding and accessing datasets
- Data curation, ontologies, and metadata
- Managing data: introduction to data warehouses and tools
- Data wrangling and Methods 101: asking a simple question of data

Pathak (5 days, grad+)
- data and knowledge representation standards;
- information extraction and natural language processing;
- visualization analytics;
- data mining and predictive modeling;
- privacy and ethics; and
- applications in comparative effectiveness research and population health research and improvement.
Shojaie (13 days, grad+)
- Accessing Biomedical Big Data
- Data Visualization
- Supervised Methods for Statistical Machine Learning
- Unsupervised Methods for Statistical Machine Learning
- Reproducible Research for Biomedical Big Data

Chuang (5 days, instructors)
- Introduction to Biology Big Data Resources
- Genomics Data Processing
- Evaluation of Data Processing with Annotation Challenge
- Integration of Heterogeneous Genomic Data with Mutation Calling Challenge

Fowlkes (5 days, grad+)
- Introduction to BIG DATA: challenges and applications
- BIG DATA Image Acquisition (ex: uSPIM)
- Physics & Mathematical Frameworks
- Basics of Image Processing
- Machine learning frameworks
- Computer Vision
- Data Mining
- Data Visualization
- High-performance computing
- Dissemination – research access; data warehousing (archiving)

Hoffman (40 days, undergrad)
- Introduction to UNIX command-line
- Next-generation Sequencing Analyses: a Primer for Biologists
- Galaxy Platform for NGS Data Analysis
- Introduction to R and Bioconductor
- Python
- Short read mapping – QC, alignment to reference and quantification
- Informatics for RNA-sequence Analysis
- Statistical Genomics
- Systems Biology and Network Analysis Methods
- Analysis of ChIP-seq data
- Variant-Calling with GATK

Kovatch (10 days, grad students)
- Introduction to UNIX
- Introduction to Computing and Data
• Introduction to Scripting
• Introduction to Python
• Overview of the Human Genome and Genetic Variation
• Genome Technologies
• UCSC Genome Browser
• Galaxy and Galaxy Toolkit
• Introduction to Next Generation Sequencing
• Genomic pipeline tools
• Genomics in the Clinic
• Analysis of rare variant/exome datasets
• Isoform-level analysis of RNA-seq datasets

Mukherjee (20 days, 3 hours per day didactic, undergrads)
• Data Acquisition, Database Management
• Common computing platform, Linux environment
• Data Structure
• Data Visualization
• Probability and Statistical Inference
• Cloud, Parallel and Distributed Computing
• Optimization
• Sampling Methods: Markov chain Monte Carlo
• Medical Informatics/Computing
• Matrix Computation
• Bias and Confounding, Missing Data, Causal Inference with Electronic Health Records
• Machine Learning, Graphical Models, Sparse Learning with Matrices, Social Network Analysis, Imaging
• Case studies in Big Data Using Python
• Computational Genomics

Recht (10 days, researchers)
• Principles of Big Data Analytics
• Applications of Big Data Analytics
• Decision Analysis
• Cost Effective Analysis
• Evidence Synthesis

Shaw (7 days, researchers)
• Introduction to Population-Scale Genomics Studies of Environmental Stress.
• Environmental Genomics
• Philosophy of Genome Science
• Experimental Design
• Sequence Data Workflow
• Comparative Transcriptomics and Population Genomics
• Sequencing Technology, its Strengths and its Limitation
• De novo Genome Assembly and Analysis in a Time of High Throughput Genomics
• RNA-Seq Alignment to Individualized Genomes
• Statistical Considerations for Analyzing Genome-Scale Big Data
• Genomes as an Environmental Indicator
• Exploring Genome Sequence Variation
• Population Genomics (Why it Differs from Population Genetics?)
• Introduction to R
• Visualization of Sequence Data for Quality Assurance
• Visualizing Complex Data
• Navigating the Command Line
• RNA-Seq Data Analysis Workshop Using Tophat and R Bioconductor
• Gene Set Enrichment Analysis
• Biological Inference Using Pathway and Network Analysis
• Exploring Genome Sequence Variation

Zhang (10 days, researchers)
• Identifying public data resources
• Data processing
• Statistical issues
• Data visualization
• Functional analysis
• R programming
• Sequence management and visualization (Galaxy, UCSC browser)
• Comprehensive Packages (e.g. GenePattern)
• Pathway analysis
• Assessing Variant Impact on Proteins
• Computational Challenges (management, storage, and parallel computing)
• Bayesian statistics
• Ethical Issues
• Team Science

Samore (12 weeks summer program, undergraduates, graduates, medical students, basic and clinical faculty)
• Computation
• Representation
• Visualization
• Analysis
Owzar (6 week summer course, advanced undergraduates, graduates and postdoctoral fellows)
  • Case studies used: Human Microbiome Project and Cancer Genome Atlas
  • Analyzing next generation sequencing data

Vitek (2 week, graduate students and postdoctoral fellows)
  • Mass spec and nuclear magnetic resonance
  • Modular format
  • R programming
  • Process mass spec, metabolomic, and proteomic data
  • Statistical methods for designing experiments
  • Hands-on sessions
# Appendix D: Summary of R25 Courses and Open Educational Resources

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<td>Integrated Active Learning Framework for Biomedical BD2K</td>
<td>University of California Los Angeles Graduate Students and Beyond</td>
<td>2014</td>
<td>Big Data</td>
<td>Graduate Students and Beyond</td>
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<td>Big Data Coursework for Computational Medicine</td>
<td>Mayo Clinic Rochester Graduate Students and Beyond</td>
<td>2014</td>
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<td>Transforming Analytical Learning in the Era of Big Data</td>
<td>University of Michigan Undergraduate Students</td>
<td>2014</td>
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<td>Development of a Best Practices in Research Data Learning and Tools Online</td>
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<td>2014</td>
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<td>The BD2K Concept Network: open sharing of active-enabling Data Science in Biology</td>
<td>Rutgers, The State University at Mount Sinai Graduate Students and Beyond</td>
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<td>The Big DIPA: Data Image Processing and Analysis</td>
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<td>A Genome Browser On-Ramp to Engage Biologists with Big Data</td>
<td>Oregon Health &amp; Science University Graduate Students and Beyond</td>
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<td>Curriculum Development and Training for Systems Genetics</td>
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<td>2014</td>
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<td>Big Genomic Data Skills Training for Professors</td>
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<td>AN OPEN RESOURCE FOR COLLABORATIVE BIOMEDICAL DATA SCIENCE CURRICULUM ON HARVARDX</td>
<td>Harvard School of Public Health Graduate Students and Beyond</td>
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## Data Science Domains

### Data Management
- Data mining / exploration
- Data visualization

### Data Science Domain:
- Data modeling
- Data science
- Data analysis
- Data mining
- Data visualization

### Computational Sciences
- Software engineering
- Algorithms
- Optimization
- Natural language processing

### Data Science Tools
- Databases

### Data Science Methods
- Probability
- Statistics
- Advanced statistics
- Machine learning
- Experimental design
- Reproducible research
- Network models

### Other
- Ethics
- Team science
- Privacy and clinical issues
<table>
<thead>
<tr>
<th>Grant PI Name(s)</th>
<th>All Institution</th>
<th>Target Audience(s)</th>
<th>Deliverable(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MARKOWITZ, DINA</td>
<td>UNIVERSITY OF ROCHESTER</td>
<td>High school students and teachers. Formal (classroom) and teacher professional development</td>
<td>Our “Big Data” curriculum module involves students in investigating how data (small data sets and “big data”) is used to study the effectiveness of calcium dietary supplements in preventing osteoporosis. We anticipate that students (and teachers) will learn about the use of big data in research and how to interpret data.</td>
</tr>
<tr>
<td>WYSS, J MICHAEL</td>
<td>UNIVERSITY OF ALABAMA AT BIRMINGHAM</td>
<td>Middle and High School teachers and students.</td>
<td>Grand Challenge Competitions in which classrooms will compete for top prizes for accuracy of data entry, creativity of hypotheses and final analysis for the data. Students will also be able to win prizes for their participation in the extraction of data.</td>
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<tr>
<td>MICKLOS, DAVID</td>
<td>COLD SPRING HARBOR LABORATORY</td>
<td>High school teachers and students.</td>
<td>This supplement aims to provide teachers and their students with the tools and knowledge to participate in all aspects of the process, from study design, through sample collection and biochemistry, to data and metadata wrangling and analysis. The notebook can be accessed and modified by users remotely from a dedicated Jupyter hub deployed at the DNALC.</td>
</tr>
<tr>
<td>IMONDI, RALPH (contact); SANTSCHI, LINDA ANITA</td>
<td>COASTAL MARINE BIOLABS</td>
<td>Secondary and post-secondary educators and students. Educational Setting: Formal (predominantly as part of research classes) and ISE (informal science education/outside the classroom)</td>
<td>Creation and deployment of a customized, student/classroom-focused student data interface to the Cell Image Library-Cell Centered Database (CIL-CCDB). Supported, in part, by the National Institute of General Medical Sciences (NIGMS), the education section of the grant is intended to advance research, education, and training, with the overarching goal of improving human health.</td>
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<tr>
<td>HODGES, GEORGIA</td>
<td>UNIVERSITY OF GEORGIA</td>
<td>Elementary learners and teachers in grades three through five.</td>
<td>The Systems project team utilized the funding from BD2K to create a digital extension that integrates the concept of analysis and use of big data in an immersive learning environment that addresses diabetes and obesity in the US. In addition to assessing the impact of the project, we are also using our experience to guide the design of the digital learning environment for future implementation.</td>
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<tr>
<td>WOOD, CHARLES ARTHUR</td>
<td>WHEELING JESUIT UNIVERSITY</td>
<td>High school students, Grades 9-12, high school biology teachers, and high school computer science teachers</td>
<td>Formal: Testing and use will take place in schools. Pandem-Data deliverables will be disseminated on the Pandem-Data website (<a href="http://www.pandemsim.com/data">www.pandemsim.com/data</a>) including: (1) A curriculum package of lesson and activities that explores and uses Big Data within the context of infectious disease. (2) A series of curriculum activities that engage students in analyzing and modeling infectious disease data. (3) A case study that demonstrates the application of developmental evaluation in a real-world context. (4) A set of resources for teachers to use in their classrooms. (5) Development of a case study using the developmental evaluation approach.</td>
</tr>
</tbody>
</table>
Appendix F: Core Courses in BD2K Training Programs, by Institution

In FY15, BD2K received 24 distinct applications for Biomedical Big Data training programs and 4 resubmissions. Of these, BD2K funded 6 applications (Columbia, Northwestern, Ohio State, UCLA, UNC, UW) that scored well in review and where each of the trainees in the program would satisfy requirements in the 3 areas. In FY16, we received 29 applications, all of which were new T32 programs. BD2K funded 10 of these applications, all of which scored well in review and were in line with the expectations set forth in the FOA.

Columbia
- Reproducibility
- Health data science (probability, network/spatial/time series modeling, clustering and classification)
- CS applications in Healthcare
- Algorithms
- Probability/Statistics
- Medicine
- Machine learning
- EDA/visualization

Dartmouth
- Bioinformatics
- Algorithms
- Probability and statistics
- Regression and multivariate statistics
- Epidemiology (experimental design)

Harvard
- Probability
- Statistics
- Methods (Linear Models and Categorical Data Analysis)
- Regression and Statistical Learning
- Data structures and Algorithms
- Health data science
- Computing foundations

Northwestern (core + selectives, competencies that can be fulfilled by a variety of courses)
- Core: Predictive Analytics, Data Mining, Advanced Computing
• Selectives: Domain knowledge, statistics, programming, ontologies, databases, text analytics
• Programming bootcamp

Ohio State University (in addition to the biomedical informatics core curriculum)
• Data Science methods in Biomedicine (data management) and 2 out of the following 3 courses
• Visualization and Machine Learning
• Advanced Modeling (HMM, spatial, network, graphical, dynamic)
• Advanced Computing (HPC)

Pennsylvania State University
• Machine Learning and Predictive Modeling
• Data Management
• Data Privacy
• Big Data Analytics
• Biomedical and Life Sciences
• Data Science electives

Stanford University (quarter system):
• Intro to Comp Bio and Bioinformatics
• Modeling Biomedical Systems
• Numerical Methods
• Statistical Inference
• Algorithms
• Object Oriented Systems Design
• Ethics
• Probability
• Data Driven Medicine
• Translational Bioinformatics
• Intro to BMI research methods
• Machine learning
• Discrete data analysis
• Unsupervised learning

University of California, Berkeley (in addition to home department requirements)
• R, Python, Parallel Computing
• Data Management
• Statistical Learning
• Data mining
• Statistical Computing
• Causal Inference
• Targeted Learning

University of California, Los Angeles (in addition to bioinformatics core curriculum)
• 4 courses in at least 2 of 3 different areas (computer science, biostatistics, informatics)
• 2 seminars (multicore computing, parallel programming, visualization)

University of Missouri (online modules from MS in Data Science prescribed to fill gaps in student knowledge in core competencies)
• Modern data analytical techniques
• Statistical analysis
• Visualization
• Relational database
• No SQL systems
• Information retrieval

University of North Carolina (in addition to home department’s core curriculum)
• 6-wk modules with data science applications
• Additional courses in complementary departments

University of Texas Austin (courses in addition to home department requirements)
• Intro to Bio for Data Science (new)
• Tools and Techniques of Computational Sciences
• Statistical Models for Big Data (new)

University of Virginia
• Computational foundations
• Data Mining, Machine learning, Information Retrieval, Linear models, Bayesian methods, or statistics
• Networks, bioinformatics, image processing, or big data in health
• Experimental design and reproducibility

University of Washington
• Probability/Statistics
• Machine learning
• Data science (visualization, management, or a new general course)
• 3 application-area courses

University of Wisconsin (in addition to home department requirements)
• 2 statistics (e.g. statistical inference and Bayesian inference)
• 2 CS (e.g. bioinformatics and optimization)
• 2 biomedical (e.g. genomic science, biology of the mind)
Vanderbilt

- Clinical Informatics
- Bioinformatics
- Biomedical Data Science Laboratory
- Data Structures
- Algorithms
- Machine Learning
- Big Data Infrastructure
- Statistical computing
- Regression and Modeling
- Statistical Inference
- General biomedical science
Appendix G: BD2K Training Program Management Working Group

Team Members Include:

Richard Baird (NIBIB)
David Banks (NINR)
Regina Bures (NICHD)
Quan Chen (NIAID)
Sandra Colombini-Hatch (NHLBI)
Genevieve deAlmedia-Morris (NIDA)
Leslie Derr (OD)
Michelle Dunn (OD/ADDS) (Co-Chair)
Lisa Federer (OD/ORS)
Valerie Florance (NLM)
Bettie Graham (NHGRI) (Co-Chair)
Ming Lei (NCI)
Susan Lim (NCI)
Veerasamy Ravichandran (NIGMS)
Erica Rosemond (NCATS) (Co-Chair)
Cathrine Sasek (NIDA)
Carol Shreffler (NIEHS)
Erica Spotts (OD)
Jane Ye (NLM)
Xinzhi Zhang (NIMHD)