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# Incorporating Genomics and Bioinformatics across the Life Sciences Curriculum

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## Introduction

Undergraduate life sciences education needs an overhaul, as clearly described in the National Research Council of the National Academies' publication *BIO 2010: Transforming Undergraduate Education for Future Research Biologists*. Among BIO 2010's top recommendations is the need to involve students in working with real data and tools that reflect the nature of life sciences research in the 21st century [1]. Education research studies support the importance of utilizing primary literature, designing and implementing experiments, and analyzing results in the context of a bona fide scientific question [1–12] in cultivating the analytical skills necessary to become a scientist. Incorporating these basic scientific methodologies in undergraduate education leads to increased undergraduate and post-graduate retention in the sciences [13–16]. Toward this end, many undergraduate teaching organizations offer training and suggestions for faculty to update and improve their teaching approaches to help students learn as scientists, through design and discovery (e.g., Council of Undergraduate Research [www.cur.org] and Project Kaleidoscope [www.pkal.org]).

With the advent of genome sequencing and bioinformatics, many scientists now formulate biological questions and interpret research results in the context of genomic information. Just as the use of bioinformatic tools and databases changed

the way scientists investigate problems, it must change how scientists teach to create new opportunities for students to gain experiences reflecting the influence of genomics, proteomics, and bioinformatics on modern life sciences research [17–41].

Educators have responded by incorporating bioinformatics into diverse life science curricula [42–44]. While these published exercises in, and guidelines for, bioinformatics curricula are helpful and inspirational, faculty new to the area of bioinformatics inevitably need training in the theoretical underpinnings of the algorithms [45]. Moreover, effectively integrating bioinformatics into courses or independent research projects requires infrastructure for organizing and assessing student work. Here, we present a new platform for faculty to keep current with the rapidly changing field of bioinformatics, the Integrated Microbial Genomes Annotation Collaboration Toolkit (IMG-ACT) (Figure 1). It was developed by instructors from both research-intensive and predominately undergraduate institutions in collaboration with the Department of Energy-Joint Genome Institute (DOE-JGI) as a means to innovate and update undergraduate education and faculty de-

velopment. The IMG-ACT program provides a cadre of tools, including access to a clearinghouse of genome sequences, bioinformatics databases, data storage, instructor course management, and student notebooks for organizing the results of their bioinformatic investigations. In the process, IMG-ACT makes it feasible to provide undergraduate research opportunities to a greater number and diversity of students, in contrast to the traditional mentor-to-student apprenticeship model for undergraduate research, which can be too expensive and time-consuming to provide for every undergraduate.

The IMG-ACT serves as the hub for the network of faculty and students that use the system for microbial genome analysis. Open access of the IMG-ACT infrastructure to participating schools ensures that all types of higher education institutions can utilize it. With the infrastructure in place, faculty can focus their efforts on the pedagogy of bioinformatics, involvement of students in research, and use of this tool for their own research agenda. What the original faculty members of the IMG-ACT development team present here is an overview of how the IMG-ACT program has affected our

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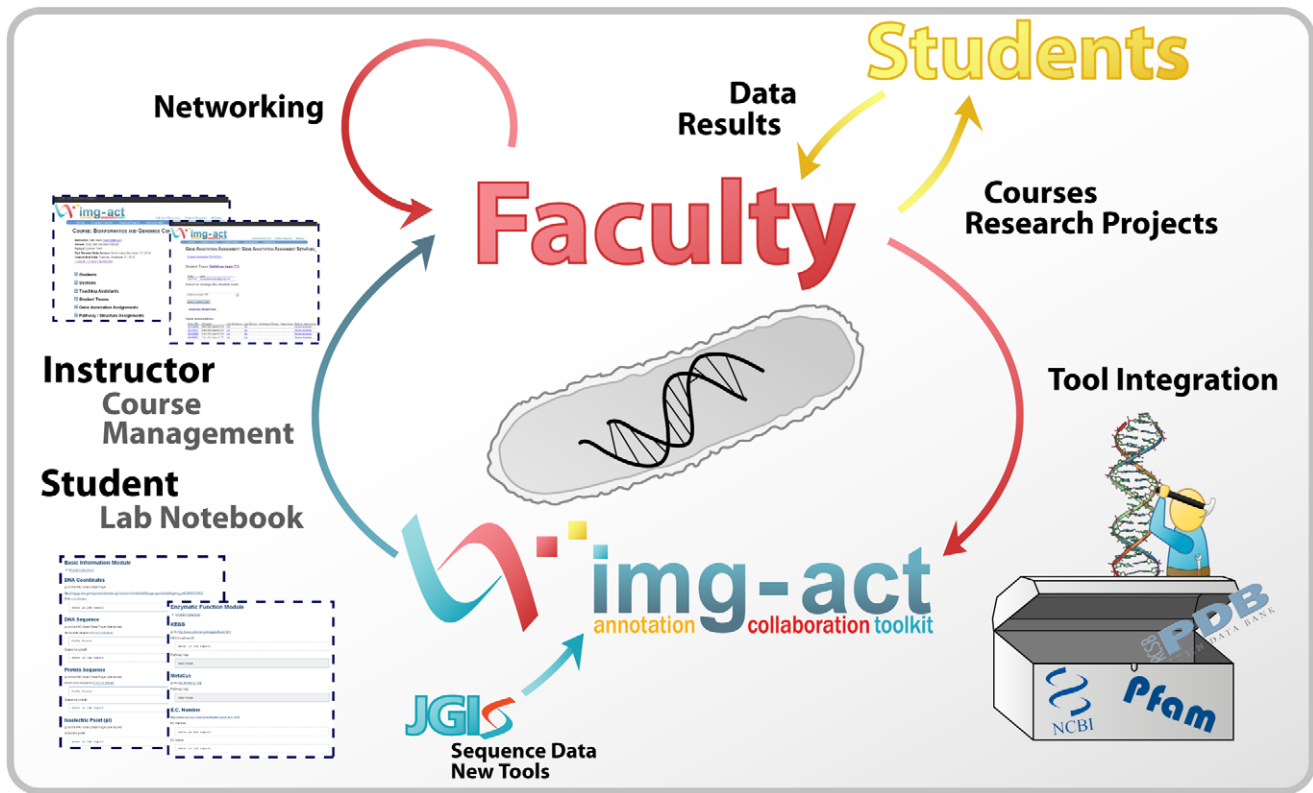
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The Community Page is a forum for organizations and societies to highlight their efforts to enhance the dissemination and value of scientific knowledge.



**Figure 1. Overview of the IMG-ACT program.** IMG-ACT was developed by instructors from diverse institutions in collaboration with the DOE-JGI. The program's purpose is to serve as a new bioinformatics platform to (1) provide faculty with sequence data and new bioinformatic tools, (2) develop on-line pedagogical tools for student data and course management, and (3) help innovate and update undergraduate education by serving as a clearinghouse for faculty networking and instruction for those new to the area of bioinformatics. Visit <http://img-act.jgi-psf.org/tour> for a tour of the IMG-ACT program, a sample annotation, and bioinformatic tutorials. To try gene annotation using the IMG-ACT tools, download a template notebook page at [http://img-act.jgi-psf.org/tour/blank\\_notebook.rtf](http://img-act.jgi-psf.org/tour/blank_notebook.rtf). doi:10.1371/journal.pbio.1000448.g001

development in terms of teaching and research with the hopes that it will inspire more faculty to get involved.

### Faculty Involved in the Project

The founding faculty members became involved in IMG-ACT for many different reasons. For some, this program was a natural extension of current work in genomics education and research [46]. These participants were drawn to a new platform with anticipated improvement in teaching and student assessment. Some without experience in the field got involved to bring new and updated course content to their curricula, either self-instigated or as mandated by departmental curricular reform. Regardless of the impetus, the common goal for everyone involved was to participate in a unique faculty development opportunity to incorporate novel research into undergraduate coursework. Appointments ranged from a post-doctoral associate, to lecturers, to tenure-track faculty from either predominantly undergraduate or research-inten-

sive institutions. Faculty came from a wide variety of life-science departments with teaching responsibilities in various disciplines including standard undergraduate courses in molecular biology, biochemistry, cell biology, genetics, and microbiology to more applied courses in bioinformatics, genomics and genome annotation, and independent study and research experiences.

### Teaching Enhancement

Designed to be flexible, the IMG-ACT platform can be used to illustrate a few key concepts in an introductory course, serve as the foundation for an entire course in bioinformatics or a microbial genome annotation research project. The main goal has been to engage students in the scientific method using real data, which exposes them to the ambiguity inherent in discovering and organizing new information. For example, in introductory science courses, instructors have utilized IMG-ACT as an active learning tool for the annotation of genes to master basic molecular concepts of

gene and operon structure. In upper division courses, the IMG-ACT program has been used as a foundation for larger projects including annotating pathways or the selection of an entire genome for annotation. Such experiences drove the development of multiple new undergraduate courses at predominantly undergraduate institutions (Text S1).

Key benefits to faculty that utilize IMG-ACT are the bioinformatic networking and educational resources that are available. The Web-distributed nature of the IMG-ACT platform facilitates the exchange of resources, ideas, and experiences of talented and committed educators as well as stimulating collaboration across multiple institutions. Tutorial resources are available for anyone interested in using IMG-ACT (<http://img-act.jgi-psf.org/tour/modules>), reducing the time needed for new course development.

Due to the interdisciplinary nature of bioinformatics, IMG-ACT can be used to promote connections between science subject areas. For example, Austin College established teamwork between undergraduate microbiology and chemistry courses

on a project where the microbiology group annotated carotenoid biosynthetic pathways in *Planctomyces limnophilus* and the chemistry group purified the pigment from the reddish-colored colonies. Interestingly, although the students were able to identify genes for lycopene biosynthesis in *P. limnophilus*, experiments conducted in the chemistry course showed that the pigment produced by the organism did not appear to be lycopene but may be some other, as of yet unidentified, pigment. This is one example of how hypotheses developed from genome studies in one course might be extended to functional studies within not only the same courses, but also in other disciplines as well.

To reflect the learner-centered nature of using gene annotation to teach undergraduates, the use of IMG-ACT has resulted in the incorporation of new teaching pedagogy at various institutions. At UCLA, an interdepartmental laboratory curriculum is under development in which all life science majors participate in a research experience, and annotation using the IMG-ACT platform was chosen as one means to reach this goal. To manage the large group of students engaging in annotation, UCLA is using peer-mentoring instruction [47–50], in which two or three students meet with instructors for annotation tutorial instruction and develop tutorials (which are available on the UCLA website at <http://www.mimg.ucla.edu/faculty/sanderslorenz/education.html>) to present to their classmates. This approach provides each lab section with at least one student “expert” on the annotation tools and concepts and builds the idea of team learning: students mentor one another and build a community of local peer experts in bioinformatics, modeling that science is a collaborative effort.

## Research Development

Faculty participation in the IMG-ACT program has also been instrumental in the

## References

1. National Academy of Sciences (2003) BIO 2010: Transforming undergraduate education for future research biologists. Washington, D.C.: National Academy Press.
2. Lopatto D (2004) Survey of Undergraduate Research Experiences (SURE): first findings. *Life Sci Educ* 3: 270–277.
3. Bain K (2004) What the best college teachers do. Boston, MA: Harvard University Press.
4. McKeachie WJ (2002) McKeachie’s teaching Tips. Boston, MA: Houghton Mifflin Company.
5. Seymour E, Hunter AB, Laursen SL, DeAntoni T (2004) Establishing the benefits of research experiences for undergraduates in the sciences: first findings from a three-year study. *Sci Educ* 88: 493–534.

enhancement of faculty research (see Text S1). Involvement with IMG-ACT has either helped support current research programs or has opened new avenues of research for some involved with the project. In addition, the use of IMG-ACT for undergraduate research can be used to strengthen the broader impacts of research agendas. Student annotations have generated preliminary data for research grant proposals, and the educational and outreach strengths of the IMG-ACT program contribute to the promotion of teaching, training, and learning and enhance the infrastructure of research and education in building networks and partnerships between universities. The National Science Foundation recently funded a collaborative research grant between the University of St. Thomas and the University of California, Davis (Proposal 0919930) whereby St. Thomas undergraduates are responsible for the annotation of the *P. putida* F1 genome and of target genes identified in toluene-induced microarray analysis. In addition, these students will be responsible in part for the functional genomics research projects that evolve from these various annotations. Due to the sheer volume of genomes that are available for annotation, the breadth of genomes in terms of representative domains and the diversity of lifestyles that the DOE-JGI Genomic Encyclopedia of Bacteria and Archaea (GEBA) ([51,52], see also [www.jgi.doe.gov/programs/GEBA/pilot.html](http://www.jgi.doe.gov/programs/GEBA/pilot.html)) project offers, the number of new research possibilities is virtually endless.

## Conclusion

We have described a new paradigm for faculty development and undergraduate education in Bioinformatics. IMG-ACT is a response to the need to update undergraduate curriculum with genomics and bioinformatics by combining genome analysis with instruction. This collabora-

tive platform meets established goals in pedagogy of the scientific method while providing an authentic research experience. IMG-ACT provides affordable instructional resources and a plethora of future uses for educators/researchers in all academic arenas. The system is continually evolving in response to the needs of its registered users; they are able to make feature requests for the system that are implemented in frequent updates (averaging six releases per year). Involvement in, and interaction with, the IMG-ACT program has also produced unanticipated benefits for the faculty (see Text S1). Since its development in 2008, the IMG-ACT system has been used by nearly 100 faculty members and over 1,600 students nationwide. To explore the IMG-ACT system and annotate an IMG gene of your choice, visit <http://img-act.jgi-psf.org/user/login>. To apply to participate in the faculty training, visit <http://www.jgi.doe.gov/education/genomeannotation.html>.

## Supporting Information

### Text S1 Course development, grant proposals, and other corollary benefits enabled by the program.

Found at: doi:10.1371/journal.pbio.1000448.s001 (0.03 MB DOC)

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6. Fox MA, Hackerman N, eds. (2001) Evaluating and improving undergraduate teaching in science, technology, engineering, and mathematics. Washington, D.C.: National Academy Press.
7. Bransford JD, Brown AL, Cocking RR, eds. (1999) How people learn: brain, mind, experience, and school. Washington D.C.: National Academy Press.
8. Donovan MS, Bransford JD, Pellegrino JW, eds. (1999) How people learn: bridging research and practice. Washington D.C.: National Academy Press.
9. Barell J (2007) Problem-based learning: an inquiry approach. Thousand Oaks, CA: Corwin Press.
10. Audet RH, Jordan LK, eds. (1999) Integrating inquiry across the curriculum. Thousand Oaks, CA: Corwin Press.
11. Hoskins SG, Stevens LM (2009) Learning our L.I.M.I.T.S.: less is more in teaching science. *Adv Physiol Educ* 33: 17–20.
12. Michael J (2006) Where’s the evidence that active learning works? *Adv Physiol Educ* 30: 159–167.
13. Nagda BA, Greggerman SR, Jonides J, von Hippel W, Lerner JS (1998) Undergraduate student-faculty research partnerships affect student retention. *Rev Higher Educ* 22: 55–72.
14. Kremer JF, Bringle RG (1990) The effects of an intensive research experience on the careers of talented undergraduates. *J Res Dev Educ* 24: 1–5.
15. Hathaway RS, Nagda BA, Greggerman SR (2002) The relationship of undergraduate research participation to graduate and professional educa-

- tion pursuit: an empirical study. *J Coll Student Dev* 43: 614–631.
16. Lopatto D (2007) Undergraduate research experiences support science career decisions and active learning. *CBE Life Sci Educ* 6: 297–306.
  17. Campbell AM, Heyer JL (2007) *Discovering Genomics, Proteomics, and Bioinformatics*, 2nd edition. San Francisco, CA: Benjamin Cummings.
  18. Hack C, Kendall G (2005) Bioinformatics: current practice and future challenges for life science education. *Biochem Mol Biol Educ* 33: 82–85.
  19. Ranganathan S (2005) Bioinformatics education—perspectives and challenges. *PLoS Comput Biol* 1: e52. doi:10.1371/journal.pcbi.0010052.
  20. Cohen J (2003) Guidelines for establishing undergraduate bioinformatics courses. *J Sci Ed Tech* 12: 449–455.
  21. Altman RB (1998) A curriculum for bioinformatics: the time is ripe. *Bioinformatics* 14: 549–550.
  22. Saier MH (2003) Answering fundamental questions in biology with bioinformatics. *ASM News* 69: 175–181.
  23. Konopka A (2004) Systems biology— not brand new, but different. *ASM News* 70: 163–168.
  24. Krilowicz B, Johnston W, Sharp SB, Warter-Perez N, Momand J (2007) A summer program designed to educate college students for careers in bioinformatics. *CBE-Life Sci Educ* 6: 74–83.
  25. Feig AL, Jabri E (2002) Incorporation of bioinformatics exercises into the undergraduate biochemistry curriculum. *Biochem Mol Biol Educ* 30: 224–231.
  26. Butler PJ, Dong C, Snyder AJ, Jones AD, Sheets ED (2008) Bioengineering and bioinformatics summer institutes: meeting modern challenges in undergraduate summer research. *CBE-Life Sci Educ* 7: 45–53.
  27. Carson S (2007) A new paradigm for mentored undergraduate research in molecular microbiology. *CBE-Life Sci Educ* 6: 343–349.
  28. Robertson AL, Phillips AR (2008) Integrating PCR theory and bioinformatics into a research-oriented primer design exercise. *CBE-Life Sci Educ* 7: 89–95.
  29. Bednarski AE, Elgin SCR, Pakrasi HB (2005) An inquiry into protein structure and genetic disease: introducing undergraduates to bioinformatics in a large introductory course. *Cell Biol Educ* 4: 207–220.
  30. Brame CJ, Pruitt WM, Robinson LC (2008) A molecular genetics laboratory course applying bioinformatics and cell biology in the context of original research. *CBE-Life Sci Educ* 7: 410–421.
  31. Honts JE (2003) Evolving strategies for the incorporation of bioinformatics within the undergraduate cell biology curriculum. *Cell Biol Educ* 2: 233–247.
  32. Cooper S (2001) Integrating bioinformatics into undergraduate courses. *Biochem Mol Biol Educ* 29: 167–168.
  33. Centeno NB, Villa-Frexia J, Oliva B (2003) Teaching structural bioinformatics at the undergraduate level. *Biochem Mol Biol Educ* 31: 386–391.
  34. Almeida CA, Tardiff DF, De Luca JP (2004) An introductory bioinformatics exercise to reinforce gene structure and expression and analyze the relationship between gene and protein sequences. *Biochem Mol Biol Educ* 32: 239–245.
  35. Boyle JA (2004) Bioinformatics in undergraduate education: practical examples. *Biochem Mol Biol Educ* 32: 236–238.
  36. Buckner B, Beck J, Browning K, Fritz A, Grantham L, et al. (2007) Involving undergraduates in the annotation and analysis of global gene expression studies: creation of a maize shoot apical meristem expression database. *Genetics* 176: 741–747.
  37. Weaver T, Cooper S (2005) Exploring protein function and evolution using free online bioinformatics tools. *Biochem Mol Biol Educ* 33: 319–322.
  38. Cannata N, Merelli E, Altman RB (2005) Time to organize the bioinformatics resourceome. *PLoS Comput Biol* 1: e76. doi:10.1371/journal.pbio.0010076.
  39. Cattley S, Arthur JW (2007) BioManager: the use of a bioinformatics web application as a teaching tool in undergraduate bioinformatics training. *Brief Bioinform* 8: 457–465.
  40. Tolvanen M, Vihinen M (2004) Virtual bioinformatics distance learning suite. *Biochem Mol Biol Educ* 32: 156–160.
  41. Campbell AM (2003) Public access for teaching genomics, proteomics, and bioinformatics. *Cell Biol Educ* 2: 98–111.
  42. Chapman BS, Christmann JL, Thatcher EF (2006) Bioinformatics for undergraduates: steps toward a quantitative bioscience curriculum. *Biochem Mol Biol Educ* 34: 180–186.
  43. Miskowski JA, Howard DR, Abler ML, Grunwald SK (2007) Design and implementation of an interdepartmental bioinformatics program across life science curricula. *Biochem Mol Biol Educ* 35: 9–15.
  44. Howard DR, Miskowski JA, Grunwald SK, Abler ML (2007) Assessment of a bioinformatics across life science curricula initiative. *Biochem Mol Biol Educ* 35: 16–23.
  45. Shaffer CD, Alvarez C, Bailey C, Barnard D, Bhalla S, et al. (2010) The genomics education partnership: successful integration of research into laboratory classes at a diverse group of undergraduate institutions. *CBE Life Sci Educ* 9: 55–69.
  46. Goodner BW, Wheeler CA, Hall PJ, Slater SC (2003) Massively parallel undergraduates for bacterial genome finishing. *ASM News* 69: 584–585.
  47. Goldschmid B, Goldschmid ML (1976) Peer teaching in higher education: a review. *Higher Educ* 5: 9–33.
  48. Velez JJ, Wolf KJ, Cano J (2007) Student perceived benefits of peer-assisted instruction. *Proceedings of the 2007 AAAE Research Conference* 34: 731–733.
  49. Topping K (1988) Peer assessment between students in colleges and universities. *Rev Educ Res* 68: 249–276.
  50. Whitman NA (1988) Peer teaching: to teach is to learn twice. *ASHE-ERIC Higher Education Report No. 4*, Washington, D.C.
  51. Kerfeld CA, Simons RW (2007) The undergraduate genomics research initiative. *PLoS Biology* 5: e141. doi:10.1371/journal.pbio.0050141.
  52. Wu D, Hugenholtz P, Mavromatis K, Pukall R, Dalin E, et al. (2009) A phylogeny-driven genomic encyclopedia of Bacteria and Archaea. *Nature* 462: 1056–1060.