Undergraduate Research: Models for Student Success

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1. Department of Biomedical Sciences
2. Council for Undergraduate Research, Health Sciences Councilor
What is Undergraduate Research?

• An inquiry or investigation conducted by an undergraduate student that makes an original intellectual or creative contribution to the discipline
  • National Science Foundation, 2003
Boyer Commission - 1998

- Ernest L. Boyer, President of the Carnegie Foundation for the Advancement of Teaching

- “Many students graduate having accumulated whatever number of courses is required, but still lacking a coherent body of knowledge or any inkling as to how one sort of information might relate to others.”
The Boyer Commission concluded that research-based learning must become “... the standard for undergraduate education, noting that the ideal undergraduate education would turn the prevailing undergraduate culture of receivers into a culture of inquirers ...”

What is Undergraduate Research?

- A complimentary activity in CMB
  - Embedded and/or extra-curricular
- Intended to
  - Advance scientific understanding
  - Increase scientific skills and literacy
  - Deepen appreciation for scientific processes
  - Broaden awareness of career opportunities
Outcomes of UR

• **Scientific** (Wei & Woodin. *CBE Life Sci Educ*. 2011)
  • enhanced understanding of the scientific process
  • increased interest in science
  • Increased confidence in various scientific skills

• **Diversity**
  • Introducing more underrepresented minorities to scientific research in the classroom
# 7 Benefits of UR

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>OBSERVATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal/professional</td>
<td>Increased confidence in ability to do research and other tasks; feeling like a scientist; working relationships</td>
</tr>
<tr>
<td>Thinking and working like a scientist</td>
<td>Application of knowledge and skills; increased knowledge and understanding of science and research work</td>
</tr>
<tr>
<td>Skills</td>
<td>Improved communication, lab/field techniques, work organization, computer, reading, working collaboratively, information retrieval</td>
</tr>
</tbody>
</table>

# 7 Benefits of UR

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>OBSERVATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarification, confirmation and refinement of career/education</td>
<td>Validation of disciplinary interests; graduate school intentions; <em>increased interest for the field</em></td>
</tr>
<tr>
<td>Enhanced career/graduate school preparation</td>
<td>Authentic research experience; opportunities for collaboration/networking; résumé enhanced</td>
</tr>
<tr>
<td>Changes in attitudes toward learning</td>
<td>Undertaking greater responsibility for project; <em>increased independence</em>; intrinsic interest in learning</td>
</tr>
<tr>
<td>Other benefits</td>
<td>A good summer job; access to good lab equipment</td>
</tr>
</tbody>
</table>

3 Models of UR

• Classroom-based
  • Josh Smith, BMS 110H
• Classroom/Research Lab Hybrid
  • Rob Delong, BMS 321/Nano-Biotechnology Laboratory
• Traditional Apprenticeship
  • Scott Zimmerman, Alzheimer’s Disease Research Laboratory
UR in the Classroom

BMS 110H and BMS 558
Dr. Josh Smith
Integration of Research into the Classroom

• Goals:
  • Engage students in a research experience
    • Freshman Honors students (BMS110: Introduction to Biomedical Sciences)
    • Cell and Molecular Biology Seniors/Graduate students
      (BMS558/658: DNA Recombinant Techniques)
  • “Fishing” experiments - high risk/high reward experiments
    • Increased numbers = increased chance of success
  • Characterize genes in *Tetrahymena*
    • Confirm annotation of genome database
**Tetrahymena thermophila**

- Unicellular Eukaryote
  - Protozoan
  - Genome Sequenced 2006
    - 104 Mb
    - 27,000 PREDICTED coding genes

- 2 Nuclei
  - Macronucleus (Somatic)
    - 225 chromosomes
    - 45N
  - Micronucleus (Germline)
    - 5 Chromosomes
    - 2N

Aswati Subramanian, Miami University, Dec. 2009
Milestone Discoveries Using Tetrahymena

1. First cell whose division was synchronized, lead to the 1st insights into cell cycle control mechanisms.
2. Identification and purification of the 1st cytoskeletal motor protein (Dynein).
3. Participation in the discovery of Lysosomes and Peroxisomes.
4. One of earliest molecular descriptions of somatic genome rearrangement.
5. Nobel-prize winning discoveries
   • Telomers and Telomerase (Blackburn and Grieder 2009, in Physiology or Medicine).
   • Catalytic RNA-Ribozyme (Cech 1989, in Chemistry).
6. Discovery of the function of histone acetylation.
7. Discovery of the roles of RNA Interference-like pathway in the heterochromatin formation (RNAi).
8. The physiological roles of the posttranslational modifications (acetylation, methylation, glycylation, & glutamylation) on histones and tubulin.
Advantages of Research-based Classroom Lab

• Increased Retention Rate
  • Increase in student interest in science/program
  • Increase in critical thinking skills
    • Higher success rate in higher level science classes
  • Increase in laboratory techniques/skills for science

• Stretches Departmental Resources for Research
  • Reagents and Supplies used in classroom and research
  • Data generated can be published and presented at scientific meetings
Multi-Institution Learning Community Model

BMS110 Honors Lab: Gene Cloning Module

BMS558 DNA Recomb. Tech. Lab: Tag Protein Complex Purification

St. Olaf Undergrad. Mass Spec. Lab

Identification of Proteins involved in NER Complexes

GFP Tagging Module (Claremont BIOL170L or WashU BIOL 3492)

Localization of NER Proteins
BMS110 Lab (Honors Lab)

• Clone genes from Tetrahymena (9 weeks)
  • Bioinformatics and Literature Search (2 weeks)
  • *Tetrahymena* Genomic DNA Isolation Lab (1 week)
  • Polymerase Chain Reaction Lab (1 week)
  • TOPO Cloning & E. Coli Transformation Lab (2 weeks)
  • Construction of Plasmid Map (Gene Construction Kit) & Restriction Enzyme Digestion Design Lab (1 week)
  • Plasmid Purification & Restriction Enzyme Digest Lab (2 weeks)

• Saccharomyces Genetics Module (Making UV Resistant Mutants) - Genetic mutation, Dominance, phenotype/genotype (3 weeks)

• Mouse Dissection/Establish Primary Cell Culture (2-3 weeks)
Class demographics

• ~24 Honors College Students/Semester (Fall)
  • 69 total students (2008-2010)
    • Major: 26 Cell & Molecular (38%), 31 Other Sciences (45%); 12 Non-science (17%)
    • Year: 55 Freshman (80%), 10 Sophomore (13%), 3 Juniors (4%), 2 Seniors (3%)
    • Grades: 45 A’s, 16 B’s, 3 C’s, 1 D, and 4 Withdrawals (93% Success Rate!)
Tetrahymena Gene Cloning

- Histone Deacetylases (Sirtuins)
  - THD8, THD9, THD11, THD12, THD13, THD15, THD16
- Histone Acetyl Transferase
  - GCN5
- Ubiquitin, SUMO, & URM Pathway
  - UBA22, UBI4, URM1, UBC13, MMS2, HTR1, AOS2, UBA4
- DNA Repair Pathways
  - DMC1, RAD23, DDI1, RAD6, PHR1, PHR2, RAD4
- 20/23 Genes cloned (87% Success Rate!)
Annotate Genes on TGD Wiki
Welcome to the Ciliate Genomics Consortium, a collaborative research initiative for undergraduate students to investigate gene function in the ciliated protozoan *Tetrahymena thermophila*. The initiative is based at the Joint Science Department of the Claremont Colleges in Claremont, CA. On this website you can access results from student research on determining coding sequence, localization, and expression patterns for various *Tetrahymena* genes by searching the Gene Database. Progress on gene knockout constructions are also available.

If you would like to get involved with the consortium, please visit Getting Involved, a place where you can also download protocols.

This site is supported by the National Science Foundation.
## Students Publish Research-CGC Website

Missouri State University

### Ciliate Genomics Consortium

- **Overview**
- **Tetrahymena Facts**
- **Gene Database**
- **Research Modules**
- **Research Community**
- **Getting Involved**

### Gene Database Summary

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[Image of the Ciliate Genomics Consortium website]

[Link to the website: http://tet.jsd.claremont.edu/gene_summary.php]
Students Publish Research-CGC Website

Gene Id TTHERM_00802330

Name: UBI4
Contributor: Ann Granich of Biomedical Science in Missouri State University
Date Submitted: 2009-12-26 16:57:20
Last Modified: 2009-12-26 16:57:20
Reference: files/r55n0.pdf
Description: Gel of plasmid digest. 1.5% agarose gel of AvrII and NheI digest of pENTR::UBI4 (lanes 2-7). Band sizes for 1kb ladder (lane 1) marked with arrows. Predicted sizes of bands would yield 266, 417, and 2000 bp (marked by arrows). Lanes 4 and 6 are the best representations of this.

Expression:
Contributor: Ann Granich of Biomedical Science in Missouri State University
Collaborators:
Date Submitted: 2009-12-26 16:57:20
Last Modified: 2009-12-26 16:57:20
Reference: files/r55n0.pdf
Students Join TGC Facebook
Multi-Institution Learning Community Model
BMS558: DNA Recombinant Techniques Lab

Gene Tagging & Isolation of Protein Complexes

- 9 major techniques
- Arrangement as would occur in actual research setting
- Goal:
  - Classification of gene (Bioinformatics)
  - Expression pattern of gene (qRT-PCR)
  - Isolate interacting proteins (Blots & Gels)
    - Allows for new tags to be identified (Mass Spec.)
  - Location of the Tagged gene (GFP)
Expression of Genes using qRT-PCR
Expression after DNA Damage

THD 11 after UV Treatment
Proteome Analysis

Western Blot

Coomassie Prep Gel
Localization of GFP/RFP Tag

GFP-GCN5  RFP-THD11
Multi-Institution Learning Community Model

- BMS110 Honors Lab: Gene Cloning Module
  - BMS558 DNA Recomb. Tech. Lab: Tag Protein Complex Purification
    - St. Olaf Undergrad. Mass Spec. Lab
      - Identification of Proteins involved in NER Complexes
  - GFP Tagging Module (Claremont BIOL170L or WashU BIOL 3492)
    - Localization of NER Proteins
Transition into Independent Research

Smith Lab

Chromatin & DNA Repair
Hybrid UR Model

BMS 321/Traditional Research Lab
Dr. Rob DeLong
BMS 321/Research Lab

BMS 321 Biomolecular Interactions
Prerequisite: "C" grade or better in BMS 231. Recommended Prerequisite: concurrent enrollment in CHM 342. Concentration is on the major classes of biomolecules (proteins, nucleic acids, carbohydrates, and lipids) important in cell and molecular biology that signal, control, and regulate cellular function and the coordination of these interactions. Other topics include: biosynthesis and catabolism of biological macromolecules and related topics in biotechnology, biological nanotechnology and molecular medicine. Laboratory emphasizes hands-on experience with current techniques in biomolecular science.

Research focuses on the binding, stabilization and delivery of DNA vaccines, siRNA and splice-site switching oligomers via nanomaterials. The group currently has two main grants or projects; 1) “Anti-Cancer RNA Nanoconjugates” funded by the National Cancer Institute R15/ARRA and 2) “Gene Vaccine Nanoparticles Against Tuberculosis” which is an R01 pending to NIBIB/NIH. We’re also interested in novel liposome biomaterials as model cell membrane structures and are investigating these for their interactions with nanoparticles and nanorods.
Introductory Experiments on Biomolecules and Their Interactions

Laboratory Manual
for
BMS 321

# Lab topics

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Learning environment

- Inquiry-based
- Deliberately somewhat open-ended
- Risk of failure
- High expectations
- Highly motivated and engaged
- Accountable to each other (e.g. - solutions prep)
Allowing room to push the envelope (e.g. TLC of amino acids)
Some qualities we look for in selecting our research students

• Performance in BMS321: exhibit experimental design and critical thinking capability
• High quality written communication: well-organized, legible research notebook
• Good questions: demonstrate understanding and a step beyond
• Team player: Good fit within the group
• Leadership: in other aspects of their life and have other interests in which they excel
• Personality: competitive, yet genuine with a high degree of integrity
Our approach to training and developing student researchers

1) Usually, but not always, during the first semester (or ideally, summer), they “volunteer” to assist others in the lab.
2) They attend group meetings and begin attending grant/project or other team meetings to develop an understanding of the broader concepts.
3) We try to involve them in the peer review of a manuscript under consideration for journal publication.
4) Depending on their time and commitment, they can progress to having their own sub-project within a research team.
5) Alternatively, they get tasked with executing a critical technique, performing it routinely as “research service” to the group or our external and internal collaborators.
A Traditional Approach to UR

The Alzheimer’s Disease Research Laboratory
Dr. Scott Zimmerman
The Alzheimer’s Disease Research Laboratory

• Apprentice model of UR
• No direct connection to any course
  • Topics related to several courses
    • Physiology of Exercise Metabolism, BMS 567
    • Pathophysiology, BMS 561
    • Recombinant DNA Techniques, BMS 558
Apprentice Model of UR

• Students work with experienced researchers to learn how to produce data.
  • Progressive independence
    • Initially, close supervision
    • Later, regular interaction and guidance
    • Ultimately, independence
The Alzheimer’s Disease Research Laboratory

- Explore the impact of exercise on the AD process
  - Amyloidogenesis and plaque development
  - Intensity and timing of exercise
  - Forced versus volitional exercise
AD Lab - Student Demographics

- Since 2009
  - 3 Graduate Students
    - One male, two female
  - 17 Undergraduate Students
    - 13 BMS 498/499
    - 4 Volunteers
    - 11 Females, 6 Males
  - 3 High School Students
    - All female

Plaque Development in APP Transgenic Mice

- 6 mos. old
- 9 mos. old
- 12 mos. old
AD Lab - UR Student
Characteristics

• Dependability primary differential
• Animal care is first responsibility
  • Mundane, unpleasant
  • Critical
AD Lab - UR Student Characteristics

- Data collection secondary
- Ability to work in the group
  - Enjoyable
  - Interested
- Build on skills from previous experiences
Brainstorm

• Challenges
• Rewards
Challenges of UR

What Do We Overcome to Do This?
Challenges/Sustainability

- **Time Commitment**
  - Longer time to setup lab reagents
  - More grading responsibility
  - Sustainability Solution:
    - BMS490-Peer Instructors in the Biomedical Sciences
    - Realization that teaching and research activities combined

- **Support Commitment**
  - Increased cost of inquiry-based labs
    - BMS110 - $42.72/Honors student vs. $11.27/regular student (FY11)
    - BMS498: Undergraduate Research – lack of funding
  - Increased space requirement for research with undergraduates
Challenges/Sustainability

• Support Commitment
  • Sustainability Solution:
    • Obtain Funding for research with undergraduates
      – Travel, supplies, equipment, etc.
    • Students fees for labs for High impact learning experience

• Student preparation
  • Increased time outside of class for student success
  • Increased effort for learning
  • Sustainability Solution:
    • Communicate high expectations
    • Positive Rewards – publications, conference presentation
Rewards of UR

What Do We (and our students) Get From This?
Currently funded projects:

1) Anti-Cancer Nanoconjugates (NIH/NCI R15 AREA)
2) MRI-RUI: Acquisition of a Micro-Raman-Photoluminescence Instrument for Materials-Related Research and Education (NSF)
3) Application of aptamer nanoconjugates as novel cancer diagnostic tools (patent and partnership with St. Johns/Inveno/Mercy Health)

Other projects where funding is pending:

1) Anti-TB DNA Vaccine Nanoparticles (NIBIB, R01 pending)
2) Nanoconjugate interactions on model liposome membranes (NSF/RUI)

Undergraduate research in the DeLong lab
Research groups:

2010 – 2011 Research Group
National Cancer Institute / "Anti-cancer RNA Nanoconjugates":
Students working on this project: Kristin Flores, Ashley Schaeffer, Chris Reynolds, Brooke Jones, Yaneika Malcolm, Mohammed Abdelhakeim, John Black, Jiang Li, Lisa Cillessen and Stephanie Barber
National Science Foundation Project/”Biomaterials”
Students working on this project: Masaaki Kanomata, Juan Reyes-Reveles, Azure Risor, Jiang Li, Brooke Jones, John Dean, Joseph McGreevy, Kelsey Chown
National Institute of Bioimaging and Bioengineering/”DNA vaccine nanoparticles”
Students working on this project: Alyssa Irlmeier and Kristin Flores

2009 – 2010 Research Group
National Cancer Institute / "Anti-cancer RNA Nanoconjugates":
Students working on this project: Hannah Gann, Matt Warner, Laramie Pence, Stephanie Barber, Chris Reynolds, Jenna McNew, Lisa Cillessen
National Science Foundation Project/”Biomaterials”
Students working on this project: Masaaki Kanomata, and Jacob Thompson.
National Institute of Bioimaging and Bioengineering/”DNA vaccine nanoparticles”
Students working on this project: Amanda Scholz-Laymon and Lisa Cillessen

2008 – 2009 Research Group
National Cancer Institute / "Anti-cancer RNA Nanoconjugates":
Students working on this project: Daniel Davis and Scott Kelsey
National Science Foundation Project/”Biomaterials”
Students working on this project: Kindra Grozinger
National Institute of Bioimaging and Bioengineering/”DNA vaccine nanoparticles”
Students working on this project: Ryan Gillihan and Curtis Bonham

Undergraduate research in the DeLong lab
Publication examples with undergraduates:


Undergraduate research in the DeLong lab
Undergraduate research in the DeLong lab
Collaborators:

- BMS (C. Witkowski, R. Garrad, and M. Craig)
- MSU (A. Wanekaya, B. Datta, K. Ghosh, and R. Herati)
- University of North Carolina (A. Hickey and R. Juliano)
- Virginia Commonwealth (G. Glaspell)
- University of Kansas (C. Russ Middaugh)
- Catholic University (A. Sarkar)
Conclusions

Why Do We Do This?
Conclusions

• Three models for UR
• Multiple entry points into research
• Research as part of the culture
• Eventually an expectation of the students
Conclusions

• UR offers students unique opportunities
  • Gain a deeper understanding
  • Apply knowledge
  • Link information
  • Think critically and deeply
  • Work collaboratively
  • Contribute to a body of knowledge


Brandon Calhoun
Alzheimer’s Association International Conference
Paris, France
July 2011
Conclusions

• UR benefits the students
  • Higher GPA
  • Increased retention
  • Greater persistence
  • Higher graduation rates

Conclusions

• UR offers faculty an opportunity to
  • Contribute to the intellectual growth of students
  • Work collaboratively with students
  • Gain assistance with current research projects
  • Generate student excitement and interest in a discipline
  • Aid students in contributing new knowledge to a field
  • Improve the quality of future applicants to the program

• UR is energizing
Council For Undergraduate Research

- [http://www.cur.org/](http://www.cur.org/)
- Institutional member
- Resources and contacts
- Program review