Evaluation Report

Graph Theory and Biological Networks Tutorial

August 16-18, 2010

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National Institute for Mathematical and Biological Synthesis
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Executive Summary

Brief Synopsis of Event

The Graph Theory and Biological Networks Tutorial took place at NIMBioS on the campus of the University of Tennessee August 16-18, 2010. This tutorial invited biologists, mathematicians and computer scientists to learn more about graph theory. Biologists learned how graph theory can inform their understanding of many common biological patterns that are in and of themselves graphs: pedigrees, fate maps, phylogenetic trees, metabolic pathways, food webs, epidemiological networks, interactomes, etc. as well as how graph theory can be used to design experiments, analyze images, and model complex interactions. Mathematicians and computer scientists learned how graph theoretical concepts such as interval graphs, planar graphs, trees, networks, Delaunay triangulations, Gabriel graphs, minimal spanning trees, etc. have widespread utility in understanding biological phenomena ranging from molecular to cellular to population levels with ecological and medical applications.

The tutorial was lead by two mathematicians and two biologists who have a long history of seamlessly borrowing from one another's disciplines. Respondents applied what they learned in lectures to actual data in a computer laboratory context by using open source, open access tools and databases.

Evaluation Design

An electronic survey aligned to the following evaluation questions was designed by the NIMBioS Evaluation Coordinator with input from the NIMBioS Director and Deputy Director:

1. Were participants satisfied with the tutorial overall?
2. Did the tutorial meet participant expectations?
3. Was the tutorial appropriate to the participants' levels of expertise?
4. Did participants feel they learned an appropriate amount of information?
5. Were participants satisfied with the amount of content and format of the tutorial?
6. Were participants satisfied with the accommodations offered by NIMBioS?
7. What changes in accommodations, group format, and/or content would participants like to see at future similar meetings?

The final instrument was hosted online via the University of Tennessee's online survey host mrInterview. Links to the survey were sent to 31 tutorial participants on August 18, 2010 (tutorial organizers and participants associated with NIMBioS were excluded from the evaluation). Reminder emails were sent to non-responding participants on August 26 and 30, 2010. By September 7, 2010, 30 participants had given their feedback, for a response rate of 97%.

An electronic demographic survey aligned to the reporting requirements of the National Science Foundation was designed by the NIMBioS Evaluation Coordinator with input from the NIMBioS Director. The final instrument was hosted online via the University of Tennessee's online survey host mrInterview. Links to the survey were sent to the 31 tutorial participants for whom NIMBioS did not have complete information on July 26, 2010. Reminder emails were sent to non-

responding participants on August 2 and 6, 2010. By August 13, 2010, 31 participants had filled out the survey for a response rate of 100%. Demographic questions regarding gender, race, and ethnicity, and disability status were optional (disability status is not reported in this evaluation report). All demographic information is confidential, and results are reported only in the aggregate. When feasible, the evaluator filled in missing demographic data from other sources (e.g. address, institution, field of study). The evaluator did not assume race, ethnicity, or disability status for any participant who did not report this information.

Highlights of Results

- The majority of respondents agreed the tutorial met their expectations (78%) and was appropriate to their level of expertise (83%).
- 93% of respondents either agreed or strongly agreed that they would recommend participating in NIMBioS tutorials to their colleagues.
- The majority of respondents (97%) thought the instructors were very knowledgeable about their topics, and 80% thought the presentations were useful.
- The majority of participants thought the hands-on exercises group discussions were useful (83%).
- 93% of respondents agreed that the format of the tutorial was very effective for achieving its goals, and 97% were satisfied with the opportunities provided during the tutorial to ask questions and/or make comments.
- The majority of respondents (87%) indicated they felt the amount of content offered during the tutorial was “just right.”
- 80% of participants agreed that they had a better understanding of how graph theory can be used to inform understanding of common biological patterns.
- A smaller majority of participants agreed that they had a better understanding of how graph theory can be used to model complex interactions (77%) and analyze images (73%) as a result of attending the tutorial.
- Overall, respondents reported being satisfied with the travel, housing, and other amenities provided by NIMBioS.

Conclusions and Recommendations

Overall satisfaction with the tutorial was high among respondents, the majority of whom indicated that the tutorial met their expectations and was appropriate to their level of expertise. Respondents were also satisfied with the travel, housing, and other amenities offered by NIMBioS.

The majority of respondents thought that the tutorial format was effective for achieving its goals and were satisfied with the opportunities provided during the tutorial to ask questions and/or make comments. Many respondents indicated the exposure to new information and ideas was the most useful aspect of the tutorial, while others liked the hands-on lab work and the ability to interact with other participants. The majority of respondents felt the amount of content covered during the tutorial was "just right." When asked what topics they would have liked to have covered in this tutorial if given more time, the most common responses were related to specific content areas (such as chemical networks, genetic networks, neuroscience applications, and phylogenetic networks), but no common themes emerged from these content area requests. Several respondents, however, indicated they would have liked to include an introductory session to the tutorial that covered terminology and background information on the topics presented.

Respondents reported the greatest knowledge gains in using graph theory to inform their understanding of common biological patterns, followed by using it to analyze images and model complex interactions. Fewer agreed that they had a better understanding of using graph theory to design experiments.

Several suggestions were made for improving future tutorials, including providing an introductory session that covered background information about graph theory, allowing for more interaction among participants, and narrowing the focus of the tutorial. Other suggestions included more hands-on sessions, longer break times, and having a poster session where participants can briefly present their work.

Based on analysis of respondent response data, the recommendations for future tutorials are as follows:

- As this was a very well-received tutorial with much interest, consider applying to host another tutorial, possibly focused on some of the topics suggested by participants in Appendix C.
- Consider offering more introductory material to participants regarding the background for research presented, methods used, and terminology of the topic area. Many participants suggested an introductory session at the beginning of the tutorial covering this information would be useful. A pre survey of participant knowledge may help uncover weak areas in participant knowledge prior to attending the tutorial.
- A common request from respondents was to break into smaller groups more often to discuss specific problems and work on projects. Consider having smaller groups work on

projects together and give mini-presentations at the conclusion of the tutorial about their work.

- Consider setting aside time at the beginning of tutorials to allow for brief participant introductions.

Graph Theory and Biological Networks Tutorial Evaluation Report

Background

Introduction

This report is an evaluation of a NIMBioS tutorial entitled “Graph Theory and Biological Networks” (Graph tutorial), which took place at NIMBioS August 16-18, 2010. NIMBioS tutorials are relatively large (30-40 participants), and serve as short introductions to particular research methods.

The Graph tutorial comprised 40 participants, including co-organizers Margaret Cozzens (Center for Discrete Mathematics & Theoretical Computer Science, Rutgers Univ.); Jo Ellis-Monaghan (Dept. of Mathematics, Saint Michael's College): Gregg Hartvigsen (Dept. of Biology, SUNY Geneseo); and John Jungck (Dept. of Biology, Beloit College).

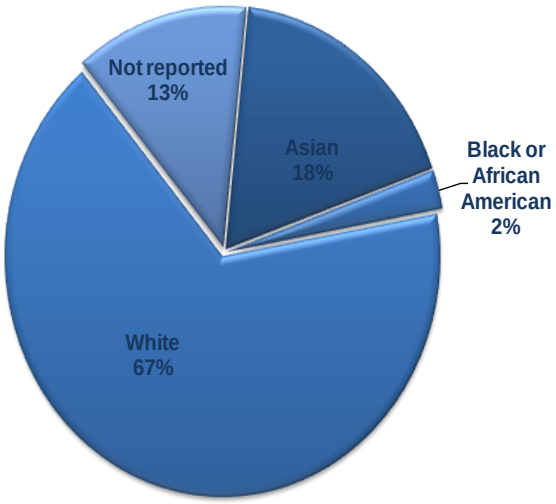
This tutorial invited biologists, mathematicians and computer scientists to learn more about graph theory. Biologists learned how graph theory can inform their understanding of many common biological patterns that are in and of themselves graphs: pedigrees, fate maps, phylogenetic trees, metabolic pathways, food webs, epidemiological networks, interactomes, etc. as well as how graph theory can be used to design experiments, analyze images, and model complex interactions. Mathematicians and computer scientists learned how graph theoretical concepts such as interval graphs, planar graphs, trees, networks, Delaunay triangulations, Gabriel graphs, minimal spanning trees, etc. have widespread utility in understanding biological phenomena ranging from molecular to cellular to population levels with ecological and medical applications.

The tutorial was lead by two mathematicians and two biologists who have a long history of seamlessly borrowing from one another’s disciplines. Participants applied what they learned in lectures to actual data in a computer laboratory context by using open source, open access tools and databases.

Participant Demographics

The 19 females and 21males (one of whom self-identified as Hispanic/Latino) came from a diverse array of racial backgrounds (Figure 1).

Figure 1. Racial composition of program respondents (n =40)



Primary fields of study for the 40 participants included agricultural sciences/natural resources, biological/biomedical sciences, engineering, and mathematics, among others (Table 1).

The majority of participants were college/university faculty, graduate students, and postdoctoral researchers; however, several participants held other positions (Figure 2).

Figure 2. Status of respondents (n= 40)

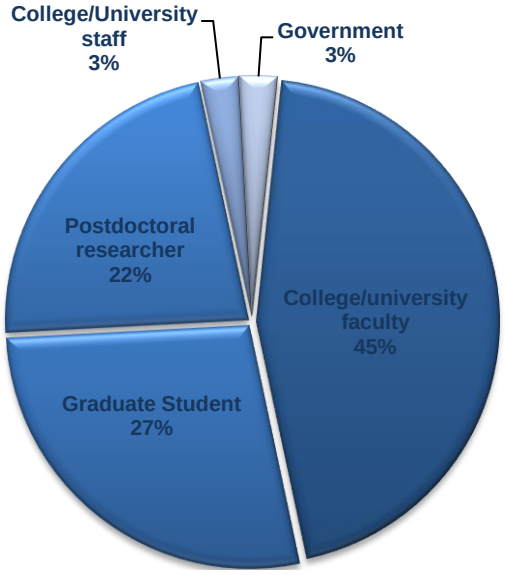


Table 1. Participant fields of study and areas of concentration

Field of Study	Concentration	# Participants
Agricultural Sciences/Natural Resources	Environmental Science	1
	Natural Resources/Conservation	1
	Wildlife/Range Management	1
Biological/Biomedical Sciences	Biophysics	1
	Botany/Plant Biology	1
	Ecology	8
	Evolutionary Biology	2
	Mathematical Biology	1
	Mathematical Ecology	1
	Zoology	1
Chemistry	Chemistry, General	1
Computer & Information Sciences	Computer & Information Science, General	2
Mathematics	Applied Mathematics	2
	Computing Theory & Practice	1
	Math/Statistics, General	5
	Mathematical Biology	4
	Mathematical Ecology	2
	Statistics	1
Ocean/Marine Sciences	Marine Sciences	1
Physics	Biophysics	1
Social Sciences	Social Sciences, General	2

Participants represented 33 unique institutions across six countries, including Austria, Canada, Nigeria, Spain, Sweden, and the United States. Within the U.S., 23 different states were represented. Included in the institutions was 1 government institution, 32 unique colleges/universities. Of the 32 colleges/universities, most were classified as comprehensive (having undergraduate and graduate programs) schools.

Evaluation Design

Evaluation Questions

The evaluation of the tutorial was both formative and summative in nature, in that the data collected from respondents was intended to both gain feedback from respondents about the quality of the current tutorial and also to inform future similar events. The evaluation framework

was guided by Kirkpatrick's Four Levels of Evaluation model for training and learning programs (Kirkpatrick, 1994[1]). Several questions constituted the foundation for the evaluation:

1. Were participants satisfied with the tutorial overall?
2. Did the tutorial meet participant expectations?
3. Was the tutorial appropriate to the participants' levels of expertise?
4. Did participants feel they learned an appropriate amount of information?
5. Were participants satisfied with the amount of content and format of the tutorial?
6. Were participants satisfied with the accommodations offered by NIMBioS?
7. What changes in accommodations, group format, and/or content would participants like to see at future similar meetings?

Evaluation Procedures

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[1] From Kirkpatrick, D.L. (1994). *Evaluating Training Programs: The Four Levels.* San Francisco, CA: Berrett-Koehler.

Data Analysis

Data from the electronic surveys included both forced-response and supply-item questions. All data were downloaded from the online survey host into the statistical software package SPSS for analysis. Quantitative data were analyzed using SPSS, while qualitative data were analyzed in SPSS Text Analysis for Surveys. Qualitative responses were categorized by question and analyzed for trends.

Evaluation Findings

Respondent Satisfaction

Overall Satisfaction

Overall satisfaction with the tutorial was high among respondents, the majority of whom indicated they either agreed or strongly agreed that the tutorial met their expectations (78%) and was appropriate to their level of expertise (83%). Some respondent comments:

> *"A fantastic workshop! The organizers and presenters did a fantastic job of answering questions and created a welcoming learning atmosphere within this group. This is not easy to do with people from different disciplines, but the problem of different "languages" of biology and math was overcome by enthusiasm of all the presenters and their openness to question."*

> *"Energetic instructors and supportive staff made it a good experience. Enjoyed the workshop!"*

The majority of respondents (97%) thought the instructors were very knowledgeable about their topics, and 80% thought the presentations were useful. The majority of respondents thought the hands-on exercises and group discussions were useful (83%) as well. Additionally, 93% of respondents either agreed or strongly agreed that they would recommend participating in NIMBioS tutorials to their colleagues (Figure 3, answered on a 5-point Likert scale from -2 to 2 for "strongly disagree" to "strongly agree").

Comments about the tutorial overall:

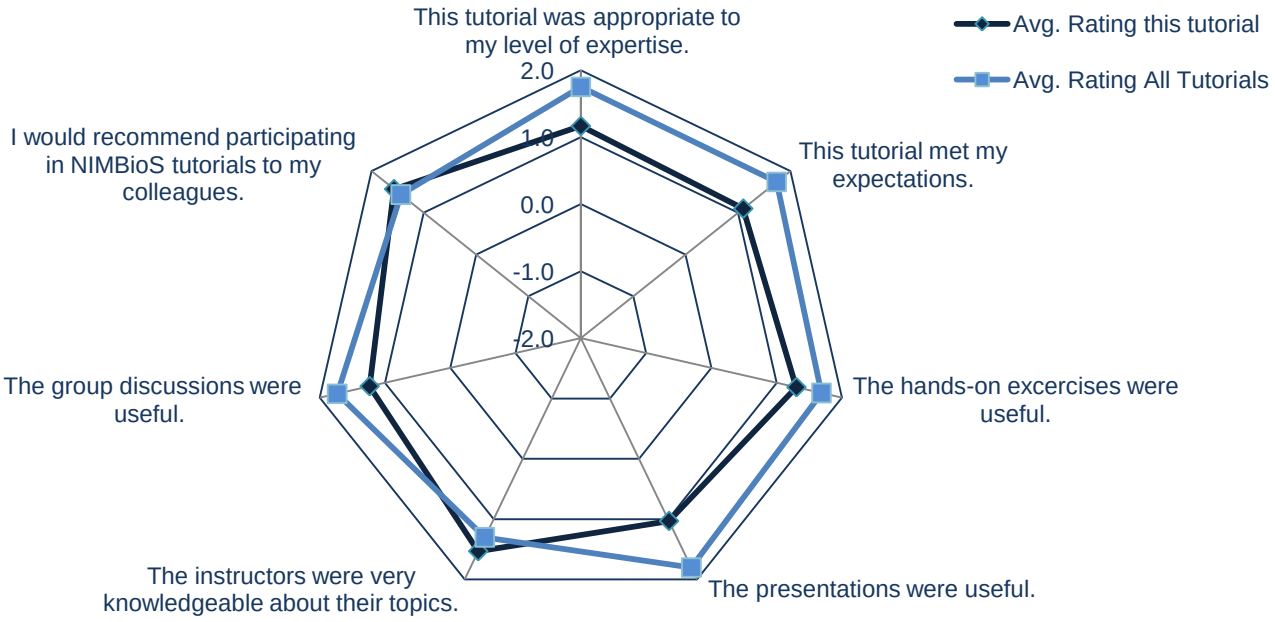
"This was a fantastic and very rewarding opportunity to meet and interact with mathematicians and people from other disciplines. This sort of cross-fertilization of ideas is extremely valuable yet often very difficult to facilitate. NIMBioS has been very effective in achieving this."

"I am glad that I came to this tutorial. I am a graph theorist and don't have any biomath research experiences. This tutorial provides a lot of information which will help me to get started….I am a little disappointed that I didn't make many connections with fellow participants."

"This was a very worthwhile opportunity. It is a rare opportunity to get to spend a concentrated amount of time learning about a new topic in such an interdisciplinary atmosphere. This workshop provided me with a more complete view of graph theory and helped expand my thinking about the types of questions it is possible to ask and answer."

"…It was really informative and interesting to learn about what types of research are being conducted in different fields that use graph theory…It certainly helped me to appreciate the applicability of graph theory, as well as the diverse areas of biology and science in which it is currently used. Thank you for holding this tutorial!"

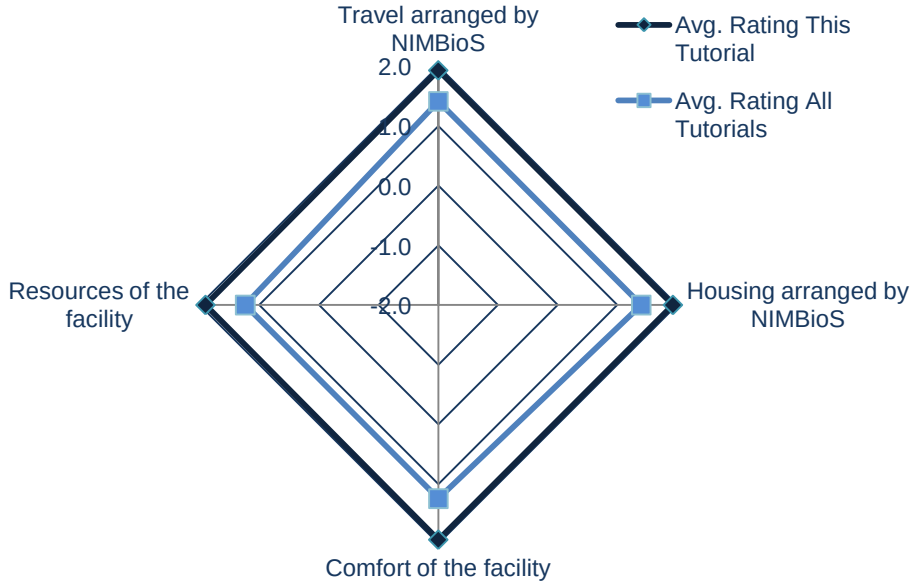
Figure 3. Satisfaction with various aspects of tutorial



Satisfaction with Accommodations

Overall, respondents reported being satisfied with the travel, housing, and other accommodations provided by NIMBioS during the Workshop. Twenty-nine respondents answered questions about their travel and housing accommodations, 28 of whom said they were very satisfied with their accommodations, while one indicated feeling "neutral" (Figure 4, answered on a 5-point Likert scale from -2 to 2 for "strongly disagree" to "strongly agree").

Figure 4. Satisfaction with accommodations



Tutorial Content and Format

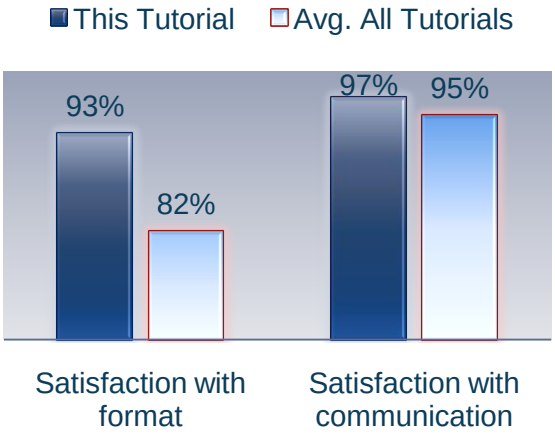
Format

The majority of respondents (93%) thought the tutorial format was effective for achieving its goals, and 97% were satisfied with the opportunities provided during the tutorial to ask questions and/or make comments (Figure 5). The only suggestions for improving the format centered on the inclusion of an introductory session at the beginning of the event:

> *"…there [should have] been a deeper primer for each of the primary groups: more basics of graph theory for biologists, and more biology for mathematicians."*

> *"Rather than starting the tutorial with examples, some history/background into graph theory would have been useful. Then move into specific case studies whereby how graphs were used for inference were explicitly identified."*

Figure 5. Satisfaction with format and communication



Several respondents provided suggestions for improving communications at future similar events, including setting aside time for participant introductions:

> *"Introducing each other at the beginning. Divide participants into groups not by where they sit, instead, by their research areas. Mix biologists with mathematicians, students with faculty and arrange this before the tutorial starts."*

> *"Take 30 minutes the first morning such that the participants present themselves in person (not on the web)."*

Others suggested breaking participants into subgroups to discuss specific research issues and applications of graph theory:

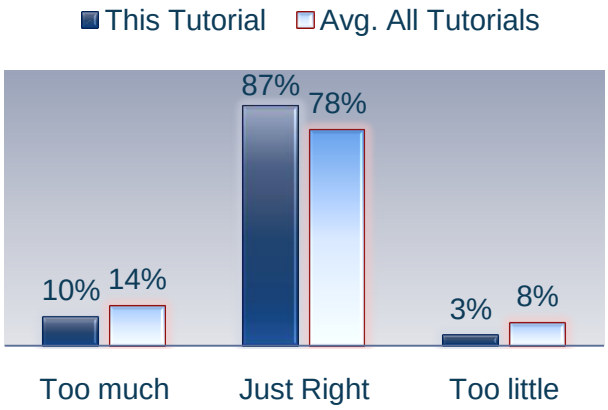
> *"Perhaps identify sub-groups with similar interests (epidemiology, food webs, etc) and devote a small amount of time to encouraging discussion within those sub-groups."*

> *"The organization of the space did make communication a little difficult. Particularly during breaks and lunch, there were not many spaces were groups of people could sit, face each other and talk. So that could have been a bit more helpful. Another way that the tutorial could have increased communication would be to have participants work in small groups on their own research issues. So if a few participants have specific problems or issues they have encountered in their own research, it might be helpful to have time to discuss those issues in small groups."*

Content

Eighty-seven percent of respondents felt the amount of content covered during the tutorial was "just right," while the remainder felt there was either "too much" or "too little" content covered (Figure 6).

Figure 6. Amount of content offered



Qualitative analysis of responses revealed that most respondents felt the exposure to new information and ideas was the most useful aspect of the tutorial (Figure 7):

[The most useful aspect was]

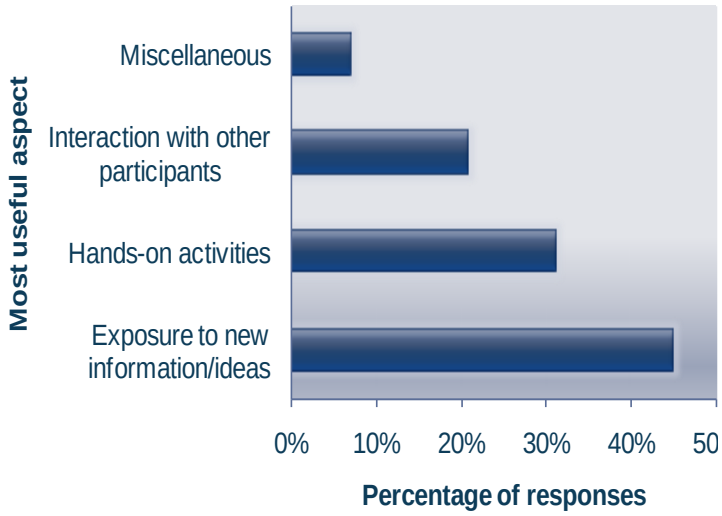
> *"Specifically, learning how useful the existing software packages can be (such as R in the construction and analysis of graphs)."*
>
> *"To get an overview of what is happening in this subject. It has inspired me to new research topics."*
>
> *"Knowing applications of graph theory in epidemiology. Use of statistical software R in graph theory Social network graphs and game theory. Learning about phylogenic tree Scale-free networks."*

Many respondents indicated the hands-on lab work was the most useful aspect of the tutorial:

[The most useful aspect was]

> *"Hands on exercises. I was shown many things that sparked ideas for future projects, particularly for use with undergraduates and in collaboration with an ecologist at my home institution."*
>
> *"Some of the hands-on exercises were really useful. Unlike most seminars & talks, I was actually able to FOLLOW and understand everything. I get the sense*

Figure 7. Most useful aspects of the tutorial



that the biologists did as well (I'm a mathematician). It's very hard to present topics like this that are both (i) advanced, and (ii) accessible / within the reach of both biologists and mathematicians. The presenters in this tutorial succeeded triumphantly with this…"

"The interactive computer labs following the lectures were great and very useful."

The third most prevalent response was the ability to interact with other participants:

[The most useful aspect was]

"Opportunity to attempt to start up collaborations with biologists (being a graph theory guy myself). Other discussions, lectures, and the R + igraph tutorial would be second most useful."

"This was a fantastic overview of applications of graph theory to biological problems. I feel I have a better grasp about the areas of overlap of the fields. I also enjoyed the diversity of participants this workshop had. I had some great conversations and hope to collaborate with some of the participants in the future."

When asked what topics they would have liked to have covered in this tutorial if given more time, the most common responses were suggestions related to specific content areas (such as chemical networks, genetic networks, neuroscience applications, and phylogenetic networks), but no common themes emerged from these content area requests (See Appendix C for individual responses). Several respondents, however, indicated they would have liked to include an introductory session to the tutorial that covered terminology and background information on the topics presented:

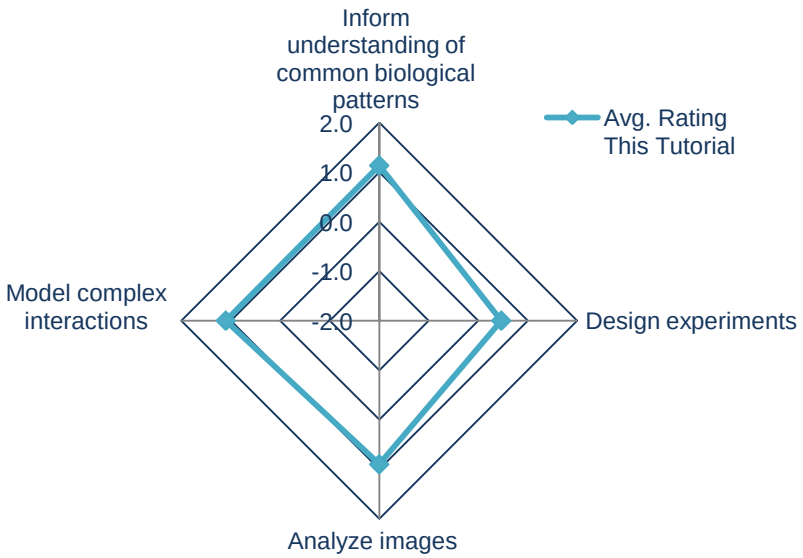
"A more comprehensive introduction at the start of the tutorial would have been useful. I don't believe the "theory" of Graph Theory was addressed. My interest is in ecological issues and that was addressed adequately given the variety of interests in the room"

"The tutorial was an effective survey of graph theory on the mathematical-biological interface and as such covered an array of topics without much depth as expected given the various background of workshop participants. The tutorial could (and probably should have) provided a more robust introduction to terminology and some of the seminal theories to get everyone on a level playing field. I would have also benefited from more details on graph theory as it relates to experimental design, spatially-explicit analysis, and network design (i.e, building a graph from scratch)."

Participant Knowledge

Respondents reported the greatest knowledge gains in using graph theory to inform their understanding of common biological patterns, followed by using it to analyze images and model complex interactions. Fewer agreed that they had a better understanding of using graph theory to design experiments (Figure 8, answered on a 5-point Likert scale from -2 to 2 for "strongly disagree" to "strongly agree").

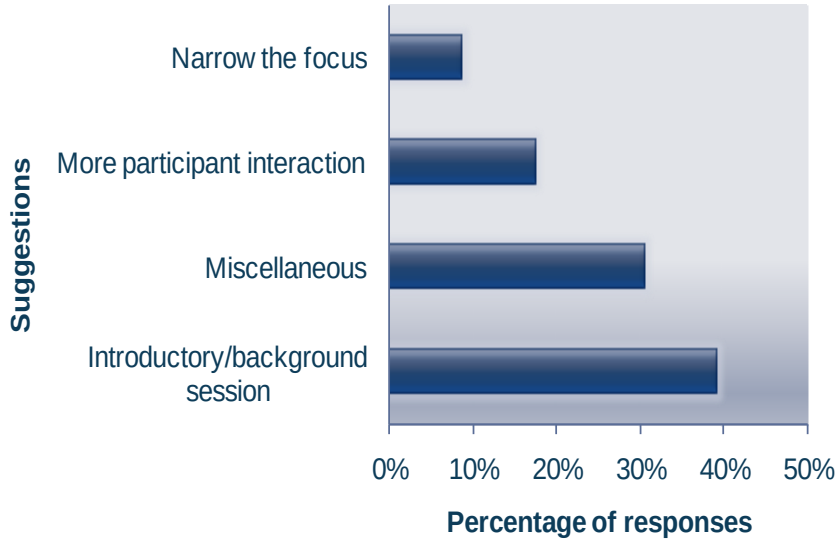
Figure 8. Participant knowledge gains



Suggestions for Future tutorials

Respondents were asked for suggestions for improving future tutorials. Several themes emerged from analysis of responses, including providing and introductory session that covered background information about graph theory, allowing for more interaction among participants, and narrowing the focus of the tutorial (Figure 9).

Figure 9. Suggestions for improving future tutorials



Comments about providing an introductory session:

"I do think that the first part of the tutorial could have given a more organized overview of graph theory. I had a basic understanding of graph theory coming into this, but got a bit lost because not all terms were clearly and slowly defined during the first few lectures. Even though many participants did have a

strong math background, I think we found that different disciplines use terms differently and so taking the time to ensure that we were all on the same page with the basic concepts and terminology from the beginning would have helped. Also some of the first labs were confusing because we were asked to answer questions without having been introduced to all the concepts first."

"[I think including a little more exposition and slowing down a bit might help. There were times when terms were flying around without definitions, leading to a little confusion."

"I wish there had been a little more communication between the presenters ahead of time. Also, one session at the very beginning to make sure all of us were on the same page with respect to terminology and core concepts."

"I would open the session with a crash course reminder about the very elementary definitions / results of graph theory."

"I would suggest including a 1 hour general introduction at the start that reviews basic concepts and terminology."

"More background and theory. More detailed examples of how to apply GT to specific problems. There should be less route "button pushing" without clear questions/problems. Many times I did not have idea why we were doing what we were doing. Often there was no clear question/hypothesis/problem that guided the presentations."

Comments about allowing for more participant interaction:

"Longer breaks in-between, therefore more time for discussions with other participants, longer in the evening. Otherwise perfect."

"Have a little more time for participants to interact between sessions Have pre-arranged groups for the group work pieces so they go more smoothly."

"It might be interesting, if the tutorial were a little longer, to have more time for discussion of research between participants."

Comments about narrowing the focus:

"Less topics and more focused or more time for each topic."

"Maybe narrow the focus a little, and allow people to choose different topics that relate to their research."

Other suggestions included having more hands-on sessions, longer break times, and having a poster session where participants can briefly present their work.

Conclusions and Recommendations

Overall satisfaction with the tutorial was high among respondents, the majority of whom indicated that the tutorial met their expectations and was appropriate to their level of expertise. Respondents were also satisfied with the travel, housing, and other amenities offered by NIMBioS.

The majority of respondents thought that the tutorial format was effective for achieving its goals and were satisfied with the opportunities provided during the tutorial to ask questions and/or make comments. Many respondents indicated the exposure to new information and ideas was the most useful aspect of the tutorial, while others liked the hands-on lab work and the ability to interact with other participants. The majority of respondents felt the amount of content covered during the tutorial was "just right." When asked what topics they would have liked to have covered in this tutorial if given more time, the most common responses were related to specific content areas (such as chemical networks, genetic networks, neuroscience applications, and phylogenetic networks), but no common themes emerged from these content area requests. Several respondents, however, indicated they would have liked to include an introductory session to the tutorial that covered terminology and background information on the topics presented.

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Based on analysis of respondent response data, the recommendations for future tutorials are as follows:

- As this was a very well-received tutorial with much interest, consider applying to host another tutorial, possibly focused on some of the topics suggested by participants in Appendix C.
- Consider offering more introductory material to participants regarding the background for research presented, methods used, and terminology of the topic area. Many participants suggested an introductory session at the beginning of the tutorial covering this information would be useful. A pre survey of participant knowledge may help uncover weak areas in participant knowledge prior to attending the tutorial.
- A common request from respondents was to break into smaller groups more often to discuss specific problems and work on projects. Consider having smaller groups work on

projects together and give mini-presentations at the conclusion of the tutorial about their work.

- Consider setting aside time at the beginning of tutorials to allow for brief participant introductions.

Appendix A

List of Participants

Participants

Last name	First name	Institution
Agusto	Folashade	NIMBioS
Beyer	Hawthorne	University of Toronto
Chen	Xiongwen	Alabama A & M University
Cho	Eungchun	Kentucky State University
*Cozzens	Margaret	Rutgers University New Brunswick/Piscataway
Dar	Roy	University of Tennessee Knoxville
Dunmyre	Justin	University of Pittsburgh
*Ellis-Monaghan	Joanna	Saint Michael's College
Ferrari	Joseph	University of Maryland Center for Environmental Science, Appalachian Laboratory
Fortin	Marie-Josee	University of Toronto
Ghosh-Dastidar	Urmi	New York City College of Technology
Gillette	Shana	Colorado State University
Gudmundson	Sara	Linkoping University
*Hartvigsen	Gregg	State University of New York College at Geneseo
Hegel	Troy	Environment Yukon, Fish and Wildlife Branch
Hsieh	Genie	University of New Mexico
Hughes	Joe	University of Tennessee Knoxville
Jhwueng	Dwueng-Chwuan	Indiana University-Bloomington
Joo	Jaewook	University of Tennessee Knoxville
*Jungck	John	Beloit College
LaMar	Michael	College of William and Mary
Linz	Simone	Technical University of Catalonia
Macauley	Matthew	Clemson University
Malcom	Jacob	University of Texas Austin
Mao	Yi	NIMBioS
Michalak	Julia	University of Washington, Seattle
Miller	Elizabeth	Michigan State University
Mokos	Jennifer	Vanderbilt University
Osnas	Erik	Princeton University
Pathikonda	Sharmila	University of Wyoming
Pelsmajer	Michael	Illinois Institute of Technology
Puckett	Brandon	North Carolina State University
Ramamurthi	Radhika	California State University San Marcos
Robic	Srebrenka	Agnes Scott College
Rockney	Alissa	East Tennessee State University
Schwab	Christine	University of Maryland Center for Environmental Science, Appalachian Laboratory
Siopsis	Maria	Maryville College
Thibert-Plante	Xavier	NIMBioS
Wright	Christopher	South Dakota State University
Zha	Xiaoya	Middle Tennessee State University

*** Organizer**

Appendix B

Graph Theory and Biological Networks Tutorial Evaluation Survey

Graph Theory and Biological Networks Tutorial Evaluation Survey

Thank you for taking a moment to complete this survey. Your responses will be used to improve the tutorials hosted by the National Institute for Mathematical and Biological Synthesis. Information supplied on the survey will be confidential, and results will be reported only in the aggregate.

Please check the appropriate box to indicate your level of agreement with the following statements about this tutorial: (Very satisfied, Satisfied, Neutral, Dissatisfied, Very dissatisfied)

The tutorial was appropriate to my level of expertise.
The tutorial met my expectations.
The hands-on exercises were useful.
The presentations were useful.
The instructors were very knowledgeable about their topics.
I would recommend participating in NIMBioS tutorials to my colleagues.

How do you feel about the amount of content offered during the tutorial?

Too little for the allotted time
Too much for the allotted time
Amount of content was just right

Please check the appropriate box to indicate your level of agreement with the following statements. As a result of participating in this tutorial, I have a better understanding of how graph theory may be used to: (Strongly agree, Agree, Neutral, Disagree, Strongly disagree)

Inform understanding of common biological patterns
Design experiments
Analyze images
Model complex interactions

What topics would you have liked to have covered in this tutorial if given more time?

What do you feel was the most useful aspect of the tutorial?

What would you change about the tutorial?

How do you feel about the format of the tutorial?
This was a very effective format
This was not a very effective format
The tutorial format would have been more effective if:

Please indicate your level of satisfaction with the tutorial accommodations:
(Very satisfied, Satisfied, Neutral, Dissatisfied, Very dissatisfied, Not applicable)

Travel arranged by NIMBioS
Housing arranged by NIMBioS
Comfort of the facility in which the tutorial took place
Resources of the facility in which the tutorial took place

Communications Evaluation

NIMBioS is currently exploring innovative avenues for communication among its tutorial participants. Your responses to the following questions will allow us to better understand the communication needs of our scientific communities.

How satisfied were you with the opportunities provided during tutorial presentations and discussions to ask questions and/or make comments?

- Very satisfied
- Satisfied
- Neutral
- Dissatisfied
- Very Dissatisfied

Please indicate any suggestions you have for facilitating communication among participants during the tutorial:

If you maintain a blog about your research and would like a link posted on the NIMBioS website, please provide the URL here, along with a brief description of the blog:

Please provide any additional comments about your overall experience with the tutorial:

Appendix C

Open-ended Survey Responses

What do you feel was the most useful aspect of the tutorial?

ecologic part

examples and software

Exposure to a broad range of applications.

exposure to aspects of graph theory I was not familiar with

Good introduction to the topics in graph theory

I learned a lot about the various measurements that graph theorists care about, and how they are applicable to my project.

Inspired participants what area of research they can apply graph theory to. Gave participants useful papers to reference to and networking with other people working on the same field.

it gave a good overview about the field

knowing about the latest applications of graph theory

Knowing applications of graph theory in epidemiology Use of statistical software R in graph theory Social network graphs and game theory Learning about phylogenic tree Scale-free networks

Learn some graph theory terms (often by simultaneously using Wikipedia) and seem some applications.

R introduction, disease transmission patterns

Specifically, learning how useful the existing software packages can be (such as R in the construction and analysis of graphs).

Talks that showed the numerous applications of graph theory

To get an overview of what is happening in this subject. It has inspired me to new research topics.

The labs.

1) interaction & networking with others in biology & mathematics (potential venues for collaboration) 2) hands on exercises w/R code

For me, the portions about food webs were the most useful. I also appreciated the "lab" portions where they introduced us to useful tools.

Hands on exercises. I was shown many things that sparked ideas for future projects, particularly for use with undergraduates and in collaboration with an ecologist at my home institution.

Some of the hands-on exercises were really useful. Unlike most seminars & talks, I was actually able to FOLLOW and understand everything. I get the sense that the biologists did as well (I'm a mathematician). It's very hard to present topics like this that are both (i) advanced, and (ii) accessible / within the reach of both biologists and mathematicians. The presenters in this tutorial succeeded triumphantly with this. I also like the email list, and the website where we can all access the slides, links, etc.

Some of the hands-on labs were useful (e.g., R lab). The most useful presentations were those that identified a question/problem, then used graph theory to address it (e.g., where to vaccinate)?

The igraph lab! All of the labs were helpful and it is so great that all the software was open source. The other most useful part was getting to meet and talk with the other participants.

The interactive computer labs following the lectures were great and very useful.

The most useful aspect of the tutorial was (1) the hands-on group and lab activities. The lectures were a nice introduction to the material and were sufficiently reinforced by the more active learning activities. (2) Submersion in graph theory terminology/vocabulary for several days was also useful for someone who interacts with colleagues that are almost unanimously speaking a non-graph theory language. I also found the content (lecture only) on my area of expertise to be useful, but would have enjoyed more time spent in that realm.

Connection to people.

I think the most useful aspect was the diversity of research interests of the participants and instructors. This allows everyone present to learn things that they would not have the opportunity to learn at their own institutions, which is very helpful to inform my individual research and knowledge of other research that is going on, as well as how to use programs like R and Biology Workbench, etc.

Interaction with mathematicians

This was a fantastic overview of applications of graph theory to biological problems. I feel I have a better grasp about the areas of overlap of the fields. I also enjoyed the diversity of participants this workshop had. I had some great conversations and hope to collaborate with some of the participants in the future.

Opportunity to attempt to start up collaborations with biologists (being a graph theory guy myself). Other discussions, lectures, and the R + igraph tutorial would be second most useful.

What would you change about the tutorial?

Less topics and more focused or more time for each topic

Maybe narrow the focus a little, and allow people to choose different topics that relate to their research.

brief introductory session including graph terminology

I do think that the first part of the tutorial could have given a more organized overview of graph theory. I had a basic understanding of graph theory coming into this, but got a bit lost because not all terms were clearly and slowly defined during the first few lectures. Even though many participants did have a strong math background, I think we found that different disciplines use terms differently and so taking the time to ensure that we were all on the same page with the basic concepts and terminology from the beginning would have helped. Also some of the first labs were confusing because we were asked to answer questions without having been introduced to all the concepts first.

I think including a little more exposition and slowing down a bit might help. There were times when terms were flying around without definitions, leading to a little confusion.

I wish there had been a little more communication between the presenters ahead of time. Also, one session at the very beginning to make sure all of us were on the same page with respect to terminology and core concepts.

I would open the session with a crash course reminder about the very elementary definitions / results of graph theory.

I would suggest including a 1 hour general introduction at the start that reviews basic concepts and terminology.

More background and theory. More detailed examples of how to apply GT to specific problems. There should be fewer routes "button pushing" without clear questions/problems. Many times I did not have idea why we were doing what we were doing. Often there was no clear question/hypothesis/problem that guided the presentations.

The tutorial could have benefited from a more robust introduction to the seminal theories and language of graph theory. I don't think much time needed to be spent on the introduction, but doing so would have helped to get everyone on the same page. Instructors of this tutorial (and probably all NIMBioS tutorials) should realize that, in line with NIMBioS' mission to aggregate scientists from a wide array of backgrounds, participants need have various levels of knowledge of the subject matter. Spending time at the beginning of the tutorial to address this would benefit all participants as the workshop progresses.

I would suggest that the biologists and mathematicians be separated for the first day to bring each group up-to-speed (as best as possible) on the opposite topic. As a biologist I was lost in some graph theoretic sections, and assume that some mathematicians were lost on certain biological topics. Coming together on days two and three, with integration of topics, could then proceed apace. Although previously stated in this survey, I would like to emphasize greater coverage of effect graphs because of the importance of causality.

As usual, I liked some of the lectures more than others. But most were really great!

I liked the structure of the tutorial.

including

Maybe turn down the A/C just a bit.

WHY would we use graph theory to answer a question? There seemed to be more discussion on the graphs, rather than why we would use them (not always the case). I left the tutorial not sure how I would actually apply this to my work. The overall structure of the tutorial was somewhat disorganized and there didn't seem to be a logical flow to the presentations. The use of jargon also distracted from the presentations. Many of us had our computers directed at Wikipedia, trying to get definitions. Frankly, there seemed to be a lot of building graphs for graphs-sake.

giving case studies

Have a survey done prior to the tutorial to find out what is the range of knowledge of the participants.

More hands on experience

Longer breaks in-between, therefore more time for discussions with other participants, longer in the evening. Otherwise perfect

Have a little more time for participants to interact between sessions Have pre-arranged groups for the group work pieces so they go more smoothly

It might be interesting, if the tutorial were a little longer, to have more time for discussion of research between participants.

more interaction and discussion among participants

The tutorial format would have been more effective if:

As noted in "Changes", there had been a deeper primer for each of the primary groups: more basics of graph theory for biologists, and more biology for mathematicians.

Rather than starting the tutorial with examples, some history/background into graph theory would have been useful. Then move into specific case studies whereby how graphs were used for inference were explicitly identified.

Please indicate any suggestions you have for facilitating communication among participants during the tutorial:

arrange evening meals at one location

inter

Take 30 minutes the first morning such that the participants present themselves in person (not on the web).

The Wiggio site was a great avenue for the participants to learn of each other's research interests. Maybe a more formal form querying the research and interests of the participants, and then letting everyone have access to the results? This might allow people to find the other participants that might be potential collaborators a little quicker (somewhat of a challenge for a 2 1/2 day workshop).

More time between sessions!

Poster session or "poster highlight" in which each of the participants gives a 1-2 minutes presentation on their work.

Structure the tutorial to confront problems often faced by math/biology teams....primarily the need to have precision and parameters for the math and the need by the biologists to address complex interactions that are often messy and ill-defined

I suppose it might be helpful to have set times when we are given time to discuss our research interests with each other; for instance, breaking into small groups and discussing research, etc. However, the Wiggio site that was used to create a group of all the participants served this purpose well, and will be very helpful in the future to contact other participants if necessary/desired.

It would have been fun to have a few short time discussion groups with a few predefined subjects. They may be suggested on Wiggio before the tutorial by the course participants or the administrators. This would have made it easier to find people with common interest in certain research topics.

More structured groups for discussion and a list of reading material or software to be looked at before the tutorial

See before, longer breaks that would allow more time of discussions among participants. Especially important in a setting like this, with people coming from various background. Good possibility to exchange ideas

I thought there was good opportunity for questions and comments both during the lectures and during the labs.

It was simply an excellent opportunity. None to suggest. I was able to communicate with several presenters and also attendees for future collaboration.

It will be better to have a couple of ecologist who use graph theory to study some interesting problems.

None; it was perfect

Perhaps a working group lunch where participants with similar research interests/topics would have been very useful especially in interpreting the graph theory tools that can be applied to those specific lunch group problems.

Perhaps identify sub-groups with similar interests (epidemiology, food webs, etc) and devote a small amount of time to encouraging discussion within those sub-groups

The organization of the space did make communication a little difficult. Particularly during breaks and lunch, there were not many spaces were groups of people could sit, face each other and talk. So that could have been a bit more helpful. Another way that the tutorial could have increased communication would be to have participants work in small groups on their own research issues. So if a few participants have specific problems or issues they have encountered in their own research, it might be helpful to have time to discuss those issues in small groups.

What topics would you have liked to have covered in this tutorial if given more time?

Greater discussion of algorithms at a conceptual level

graph methods for analyzing macro patterns

I would like to have seen some discussion on chemical reaction networks as well as a little more discussion on spatial ecological modeling such as distinguishing between the different modeling strategies and how graph theory is represented in each of them.

data visualization time series data model

dynamic, evolving networks

Foodwebs and dynamical systems

I would have liked to spend much more time on effect graphs because causality is rather important.

Experimental designs

genetic regulatory networks

A more comprehensive introduction at the start of the tutorial would have been useful. I don't believe the "theory" of Graph Theory was addressed. My interest is in ecological issues and that was addressed adequately given the variety of interests in the room.

More time for discussions between participants to learn their research work and see if collaborations are possible. Perhaps have each participant give a 5 minute précis of their research interests?

The labs were very useful. The first morning a lecture on the terminology and mathematical algorithms would have been nice. Some lectures were not reflecting the current state-of-the-art of the fields.

The tutorial was an effective survey of graph theory on the mathematical-biological interface and as such covered an array of topics without much depth as expected given the various background of workshop participants. The tutorial could (and probably should have) provided a more robust introduction to terminology and some of the seminal theories to get everyone on a level playing field. I would have also benefited from more details on graph theory as it relates to experimental design, spatially-explicit analysis, and network design (i.e, building a graph from scratch).

More theory and basic definitions and background information. Detailed application to specific problems.

More hands-on activities on analyzing graphs. I really liked the R session, and would have liked to have a bit more time to do the same with the applications combining graph theory and game theory.

More information and hands on experience on landscape analysis and phylogenetic analysis

Given more time, I would like to have had more information on how ecologists are using graph theory at the landscape level to design experiments. For example, how has graph theory been used to create testable hypotheses about ecological connectivity and flows. The labs were very useful, and although I thought there was a good balance between lecture and lab, more labs would be great, given more time.

Neuroscience applications, Auto-Immune System Response, A "get up to speed" crash course hour on the basics of graph theory may have been appropriate

The topics covered were topics I would have never thought to use graph theory for! It was very interesting, and I'm sure other topics would have been just as interesting. I think if more topics were covered, it would end up being too much information in the allotted time.

Phylogenetic analysis

phylogenetic networks

More concrete examples of how theory can be translated into experiments and step by step processes on how that is done.

More time on different terms of graph theory More on Epidemiology and graph theory More time on biological image analysis - huge information is provided in a very short time

Not sure. I know a few topics that could have been covered (reverse engineering of biological networks, bio-chemical reaction networks, different aspects of combinatorics of protein and RNA folding, Boolean networks and gene regulatory networks), but if there was more time, I'd rather hear about topics that I DON'T know about.

Some of the examples with graph theory applications could have used more support for what was learned or what the approach taught us about the system(s).

Please use this space for any additional comments:

A fantastic workshop! The organizers and presenters did a fantastic job of answering questions and created a welcoming learning atmosphere within this group. This is not easy to do with people from different disciplines, but the problem of different "languages" of biology and math was overcome by enthusiasm of all the presenters and their openness to question.

Email is still the best way to communicate with people.

Energetic instructors and supportive staff made it a good experience. Enjoyed the workshop!

For your next facility, please consider a room / projector configuration such that people in the back can see the bottom of the screen. Each day I had to move forward one row because I couldn't see through/around the heads in front of me! Otherwise, I am deeply impressed with this tutorial, it has been an incredible networking and learning opportunity.

Great workshop and venue, NIMBioS does a great job with these workshops. Being soft money funded, the provision of travel/lodging was key. Thanks!

I am glad that I came to this tutorial. I am a graph theorist and don't have any biomath research experiences. This tutorial provides a lot of information which will help me to get started. I am interested in all lectures given by four speakers. All lectures are very helpful. I am a little disappointed that I didn't make many connections with fellow participants.

I have certainly enjoyed this tutorial. It has inspired me for my future research and I have met many people that I would like to meet again for potential collaborations.

I think this tutorial was a great idea. It was really informative and interesting to learn about what types of research are being conducted in different fields that use graph theory. My previous work in graph theory did not involve applications, so it was very interesting to learn many ways that graph theory can be applied, and also to learn that only a smattering of these topics were covered at the tutorial! It certainly helped me to appreciate the applicability of graph theory, as well as the diverse areas of biology and science in which it is currently used. Thank you for holding this tutorial!

I thought this was a very positive experience. I really appreciated the size of the group, it allowed me to meet and talk to people much more easily than at larger meetings. I also really appreciated the food, I don't eat gluten and the catering was very accommodating!

It looks like I'll be starting a collaboration with someone I met here, and there are maybe other possibilities. Also I have a better idea about how to seek out and do collaborative research with biologists, as a mathematician myself, with people at my own institution.

NIMBioS provided a wonderful opportunity. I think, this is an excellent opportunity for research collaboration, to develop course module, and also learning about new topics (application of graph theory in biological problem) that opened a new area for me. I am currently thinking about developing a module for my course, and also using graph theory in epidemiological modeling.

Thank you for organizing and presenting the tutorial.

Thanks a lot for this great tutorial

Thanks to NIMBioS for hosting the graph theory tutorial. I am grateful for the chance to participate in the tutorial and for the accommodations throughout the entire process. The NIMBioS staff has been great throughout the tutorial, particularly Jennifer Thomas! The NIMBioS mission is a difficult one, but one that is very worthwhile and will benefit the scientific community of biologists and mathematicians immensely. Thanks for everything and I hope that I can make it back in other capacities in the future.

This was a fantastic and very rewarding opportunity to meet and interact with mathematicians and people from other disciplines. This sort of cross-fertilization of ideas is extremely valuable yet often very difficult to facilitate. NIMBioS has been very effective in achieving this.

This was a very well organized tutorial with great presentations. Sparked a great deal of research interest but also had many nuggets that I can use while teaching undergraduates and in outreach to high school students.

This was a very worthwhile opportunity. It is a rare opportunity to get to spend a concentrated amount of time learning about a new topic in such an interdisciplinary atmosphere. This workshop provided me with a more complete view of graph theory and helped expand my thinking about the types of questions it is possible to ask and answer.