

Group-Advantaged Training of Research (GATOR): A Metamorphosis of Mentorship

THEA M. EDWARDS, BARBARA K. SMITH, DANIELLE L. WATTS, CHARLOTTE C. GERMAIN-AUBREY, ALISON M. ROARK, SETH M. BYBEE, CLAYTON E. COX, HEATHER J. HAMLIN, AND LOUIS J. GUILLETTE JR.

We describe Group-Advantaged Training of Research (GATOR), a yearlong structured program at the University of Florida that guided graduate student mentors and their undergraduate mentees through the mentored research process. Using the national Survey of Undergraduate Research Experiences for an academic year, we found that outcomes for our mentees were similar to those for other programs. We also used an internal survey, combined with qualitative observations, to develop a road map of the mentoring process, which we call the “Metamorphosis of Mentorship.” This model provides tangible steps on the road to becoming a scientist, incorporates reasons mentees stall in research, and suggests ways to overcome mentoring challenges and prevent attrition. The structure and outcomes of this program will be useful to researchers and administrators working to engage undergraduates in scientific research, particularly at large universities where undergraduates are often mentored by graduate students.

Keywords: GATOR, mentoring, mentoring model, undergraduate research, graduate student mentors

Research indicates that mentoring benefits undergraduate science students by promoting their self-confidence, interest in science professions, maturation of scientific thought, and development of laboratory and communication skills (e.g., Lopatto 2003, Russell et al. 2007). Higher education has traditionally emphasized faculty-student mentoring relationships. However, research universities increasingly encourage graduate students to take on mentoring responsibilities, in part because of declining resources, growing costs, and greater pressures of tenure and promotion on faculty (Desai et al. 2008).

Pfund and colleagues (2006) showed that graduate students can effectively prepare for mentoring through structured training programs, such as Entering Mentoring (Handelsman et al. 2005). In addition, graduate student mentorship offers benefits to both mentors and mentees that appear comparable to traditional faculty-student partnerships (Desai et al. 2008). In particular, graduate mentors can accomplish projects with mentees that they would not be able to do alone. Further, because graduate mentors encounter the mentoring relationship from both sides simultaneously (as mentors to undergraduates and as mentees to their faculty advisers), they are in a unique position to develop perceptive mentoring skills.

The purpose of this article is to quantify the development of undergraduate mentees who were guided by graduate student research mentors. We focus on the organization and

outcomes of the Group-Advantaged Training of Research (GATOR) program, a yearlong mentoring program at the University of Florida, in which doctoral students mentored undergraduates in life sciences research (www.biology.ufl.edu/hhmi). In addition, we present qualitative insights we gained as mentors in the GATOR program. Finally, we combine our quantitative data and qualitative observations to construct a model of the mentoring process and mentee development, which we call the “Metamorphosis of Mentorship.” This model provides a road map through the mentoring process and describes tangible steps taken by students as they learn to be scientists. It also incorporates the reasons mentees may stall or lose interest in research and suggests ways to prevent undergraduate attrition from research programs. We anticipate that the structure and outcomes of the GATOR program, and the Metamorphosis of Mentorship model in particular, will be useful to researchers and administrators working to engage undergraduates in scientific research, as well as to the students themselves.

Overview of GATOR

The GATOR program (running annually from 2007 through 2010) trained both doctoral student mentors and undergraduate mentees to prepare them to become faculty mentors and graduate students, respectively. To meet this goal,

GATOR was organized into teams of two or three people, with each team consisting of a doctoral student mentor and one or two undergraduate mentees (figure 1). The 2008–2009 program year, which is the subject of this article, consisted of 10 such teams.

Graduate mentors received formal mentorship training from program directors using Entering Mentoring, a Howard Hughes Medical Institute (HHMI)–sponsored mentoring seminar (Handelsman et al. 2005). Individual teams worked on diverse research projects related to the graduate mentor's dissertation research but met as a group for program-sponsored courses in communication and the scientific process (figure 2). By creating research teams within a larger group framework, the program emphasized the importance of group interactions and support throughout the process of mentor and scientist education.

Demographics of the 2008–2009 mentor-mentee cohort

Graduate mentors ($n = 10$; 9 doctoral students, 1 postdoctoral researcher; 5 men, 5 women; 8 Caucasian, 1 Hispanic, 1 Middle Eastern; 7 American citizens, 3 international) were selected from diverse academic backgrounds within the life sciences, representing seven departments and four colleges at the University of Florida. Mentees ($n = 17$; 4 seniors, 9 juniors, 4 sophomores; 6 males, 11 females; 14 Caucasian, 1 African-American, 1 Hispanic, 1 Middle Eastern; 14 traditional-age college students, 3 nontraditional students [25, 28, and 32 years old]) were academically diverse, representing 10 majors,

including philosophy, biochemistry, environmental engineering, and several fields within biology. Mentees ranged in previous research experience from completely inexperienced (most mentees) to several years' experience in laboratory settings (one mentee).

GATOR time line

The timing of major components of the GATOR program is shown in figure 2. Program directors recruited graduate mentors in the fall semester. During the following spring semester, interested undergraduates scheduled interviews with potential mentors before applying to the program. In their applications, undergraduates identified mentors with whom they wanted to collaborate, and mentors chose mentees from this pool. This selection process is unusual among mentoring programs and has two important benefits. First, it mimics how most students apply to graduate school, and second, it allows mentors to make the final, informed decision regarding whom they invite to join their research teams. This process improved the likelihood of a good match among mentor, project, and mentee and is a different approach from the one used in most summer mentoring programs, where undergraduates are assigned to labs.

The program year officially began in May of 2008 and continued through April of 2009. Throughout the summer of 2008, mentor-led activities included reading and discussion of pertinent literature; introduction to laboratory culture, expectations, and duties; and training in specific research methodologies. Mentees spent 25 to 30 hours per week

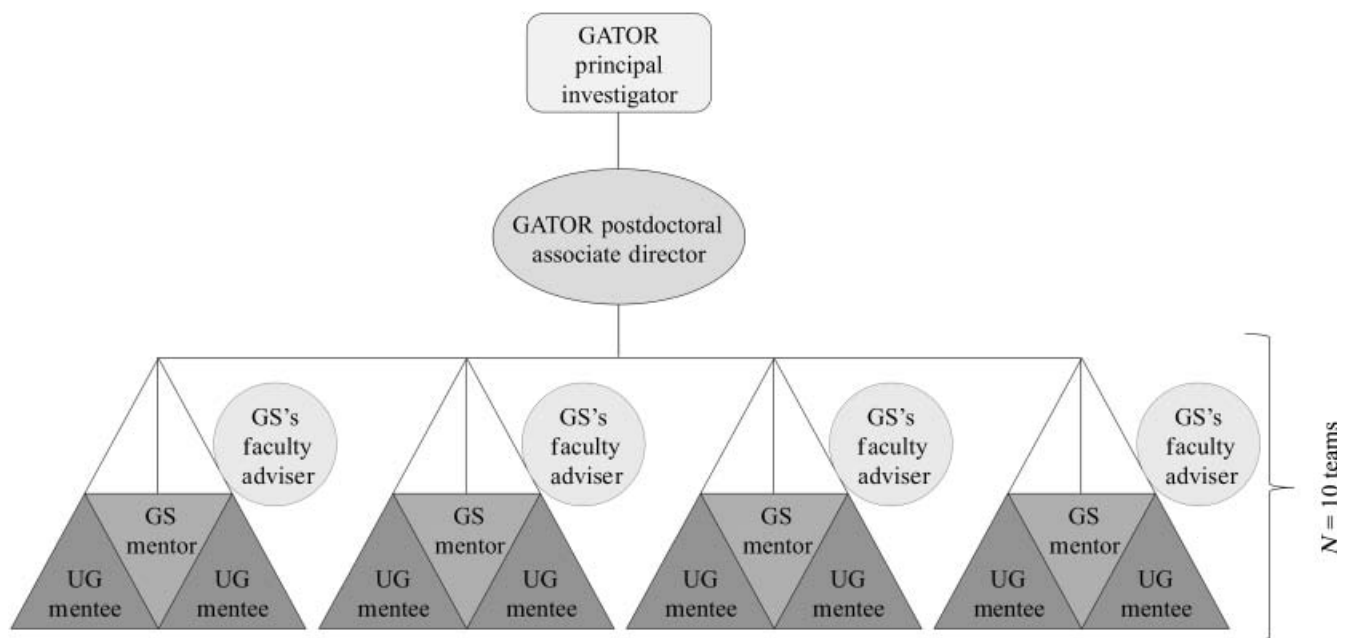


Figure 1. GATOR program personnel organization. Individual mentoring teams (large triangles) consisted of a graduate student (GS) or postdoctoral mentor and one or two undergraduate (UG) mentees who were supported as needed by the GS's faculty adviser. Each mentoring team met regularly both independently and in conjunction with other GATOR mentoring teams. The GATOR program was administered by an experienced postdoctoral mentor and the faculty principal investigator. A total of 10 mentoring teams participated in the 2008–2009 GATOR program.

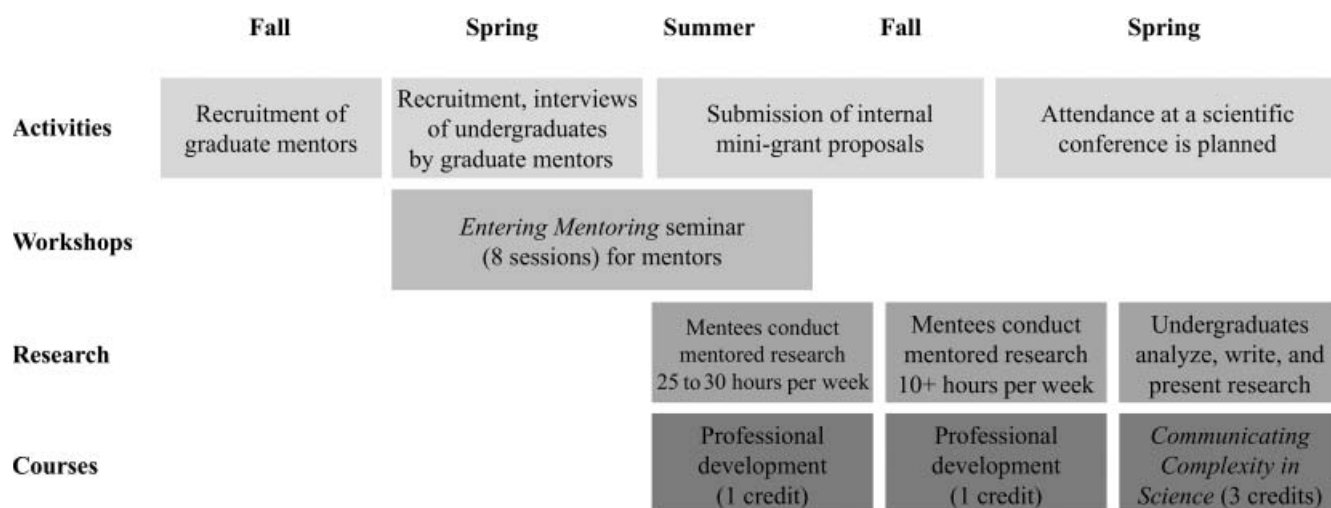


Figure 2. GATOR program time line indicating major program elements. Undergraduates scheduled interviews with prospective mentors before applying to the program, thereby emulating the graduate school application process.

engaged in scholarly activities with their mentoring teams. During this time, undergraduates worked with their graduate mentors to develop research projects and write an internally refereed and funded small grant proposal (up to \$500). Teams convened weekly in a group-based seminar on professional development. The structured summer laboratory experience culminated in short oral presentations of proposed research and preliminary data collected by the end of the summer. All participants received summer stipends to facilitate immersion in the summer research experience.

The fall semester of GATOR was designed to facilitate greater autonomy of mentees, all of whom received college credit for 10 hours per week of independent study for data collection and analysis of their research results. To foster independence within a supportive framework, individual mentoring teams met periodically to solve problems, discuss data, and analyze results. In addition, all teams continued to meet weekly for the one-credit seminar to help mentees improve scientific communication skills, develop curricula vitae, and execute statistical analyses in mentor-led, group activities. The seminar component of GATOR helped mentees transition from a period of preparation and technical skill acquisition to improved critical thinking, independence, and communication with other scientists.

The goal of the spring semester of GATOR was for mentors and mentees to achieve proficiency and confidence with written, oral, and Web-based scientific communication. All participants completed a three-credit course titled *Communicating Complexity in Science*. During this final stage of the program, participants critically assessed scientific reporting, learned techniques for professional and media interviews, networked with guest scientists, and presented poster and oral summaries of their research. To facilitate networking and external dissemination of projects, mentoring teams were encouraged to attend conferences and apply for GATOR-funded travel grants. Toward the end of the spring

semester, efforts were increasingly focused on stimulating additional mentee curiosity and team collaboration beyond the term of the program.

Evaluation of the GATOR program

We evaluated outcomes of the GATOR program using the HHMI-sponsored Survey of Undergraduate Research Experiences (SURE II) to compare GATOR with other academic-year programs across the United States. Additionally, we developed an internal survey to measure undergraduate mentee outcomes specifically for GATOR. We combined results of the internal survey with our observations as mentors to develop a generalized road map of the dual processes of mentoring and learning to be a scientist, called the *Metamorphosis of Mentorship*.

Comparison of GATOR mentees with the national average

In April 2009, at the end of the program year, mentees completed the 2008–2009 SURE survey for academic year research programs (SURE IIay). SURE IIay is a nationwide, online survey administered by Grinnell College and funded by HHMI (Lopatto 2003). Mentees completing the SURE rated their research experiences using an ordinal scale of 1 (no gain) to 5 (very large gain). Mentees' responses to 44 individual SURE questions were used to calculate mean gains in 21 areas that resulted from participation in an undergraduate research experience (table 1). We used independent *t*-tests to compare the SURE responses of GATOR mentees with those from 1733 undergraduates from across the United States who responded to the survey between 2006 and 2009 ($\alpha = 0.05$; table 1).

Findings of the SURE IIay survey. Of the 21 primary gains that were evaluated using the SURE IIay, compared with the national cohort ($p < 0.05$), GATOR mentees reported better

Table 1. Survey of Undergraduate Research Experiences for an academic year (SURE IIay) results showing GATOR program ($n \leq 17$) mentee's self-reported gains after a yearlong research experience as compared with a national cohort who responded to the survey between 2006 and 2009 ($n \leq 1733$).

Skill	GATOR mentees, 2008–2009 (mean \pm SE)	National, 2006–2009 (mean \pm SE)
Self-confidence	3.39 \pm 0.252	3.66 \pm 0.027
Ability to integrate theory and practice	3.44 \pm 0.150	3.89 \pm 0.023*
Confidence in my potential as a teacher	3.47 \pm 0.245	3.44 \pm 0.029
Ability to analyze data and other information	3.50 \pm 0.192	3.95 \pm 0.024
Skill in science writing	3.56 \pm 0.209	3.54 \pm 0.029
Learning to work independently	3.56 \pm 0.291	3.95 \pm 0.026
Readiness for more demanding research	3.78 \pm 0.228	4.07 \pm 0.022
Understanding how knowledge is constructed	3.78 \pm 0.228	3.92 \pm 0.023
Understanding science	3.78 \pm 0.213	3.85 \pm 0.025
Skill in how to give an effective oral presentation	3.78 \pm 0.243	3.60 \pm 0.031
Tolerance for obstacles in research	3.83 \pm 0.209	4.06 \pm 0.023
Becoming part of a learning community	3.88 \pm 0.209	3.82 \pm 0.026
Understanding how scientists think	3.89 \pm 0.201	3.80 \pm 0.025
Understanding how scientists work on real problems	4.00 \pm 0.221	4.10 \pm 0.023
Skill in interpretation of results	4.00 \pm 0.221	3.99 \pm 0.022
Learning ethical conduct	4.00 \pm 0.221	3.43 \pm 0.030
Ability to read and understand primary literature	4.06 \pm 0.228	3.87 \pm 0.027
Understanding that scientific assertions require evidence	4.11 \pm 0.247	3.91 \pm 0.027
Clarification of career path	4.11 \pm 0.184	3.52 \pm 0.027*
Learning laboratory techniques	4.11 \pm 0.310	4.20 \pm 0.025
Understanding the research process	4.17 \pm 0.192	4.20 \pm 0.021

SE, standard error
 Note: Asterisk indicates gains that were significantly different between GATOR mentees and the national average (independent *t*-tests, $p < 0.05$).
 Rows are organized from top to bottom in order of increasing gains for GATOR mentees.

clarification of career path but reduced ability to integrate theory and practice. No other differences were observed between the two groups (table 1). It is noteworthy that most of the 17 GATOR mentees entered the program with less prior research experience than the national cohort (GATOR program: 76% inexperienced; national cohort: 41% inexperienced). In addition, GATOR mentors included nine doctoral students and one postdoctoral fellow with little mentoring experience and no formal mentoring training prior to their participation in the program; thus, GATOR participants were less experienced on average than their national counterparts (assuming most national mentors are faculty), but achieved the same gains in research experience.

GATOR internal undergraduate survey and the metamorphosis of mentorship

To evaluate the rate and extent of skill acquisition and scientific maturation specifically emphasized by the GATOR

program, we developed a second survey on the basis of existing surveys used in undergraduate science and education (Hudson et al. 2005, Russell et al. 2007). We queried the 17 GATOR mentees to determine when they first experienced 28 specific research skills, how important each skill was to achieving their research goals, and their perceived level of skill (confidence) in each area at the end of the GATOR program (survey available in online supplementary materials appendix 1 at dx.doi.org/10.1525/bio.2011.61.4.10). We also asked mentees about their interest in pursuing scientific careers and the degree to which they participated in the development of their research questions.

Mentees estimated when they first experienced each skill using a seven-point temporal scale ranging from program initiation (early summer, time 1) to a time beyond the conclusion of the GATOR program (i.e., the mentee anticipated developing the skill after GATOR, time 7). Mentees could also choose “not at all” to indicate that they had not encoun-

tered the skill. Next, they rated the importance of each skill to their research goals, from 1 (not at all important) to 5 (very important). Finally, mentees graded their confidence with each skill upon program completion from 1 (very low proficiency) to 5 (very high proficiency) (appendix 1).

To evaluate the results of the GATOR undergraduate survey, we created box plots showing the minimum and maximum responses, means ± 1 standard error (SE), and modes of self-reported confidence and importance of the 28 targeted skills among GATOR mentees (figure 3). We did the same for the reported timing when mentees began to gain experience in each skill, having removed data points where the mentees chose “not at all,” indicating they had no experience with a given skill. We also used a linear regression to examine the relationship between mentees’ involvement in the development of their projects and their skill outcomes at the end of the year.

The University of Florida Institutional Review Board approved the survey, and informed consent was obtained from mentees. Undergraduate mentees completed the survey in April 2009 using encoded forms. The survey required approximately 20 minutes to complete.

Translation of the internal survey into a mentorship road map

To translate results of the GATOR internal survey ($n = 17$ mentees) into a graphic illustration of the mentoring relationship and mentee development, we categorized the 28 skills from the survey, a posteriori, into five progressive stages of research accomplishment (figures 3 and 4). Categories were arranged on the basis of when mentees reported skill acquisition, coupled with mentee-perceived proficiency and our qualitative observations as mentors. Although we report the results of this survey sequentially according to the five stages we identified, the survey questions were randomized when they were administered to mentees.

The qualitative component of our model represents a synthesis of numerous roundtable discussions among mentors concerning themes that were relevant for more than one research team. Mentors involved in the qualitative development of the model are also coauthors of this article, and include 6 of the 10 GATOR graduate or postdoctoral mentors from 2008 to 2009, 2 GATOR associate directors with mentoring experience (TME and AMR), and the principal investigator for the GATOR program (LJG).

The stages of our model are: (1) the beginning stage, when research teams initiate research projects; (2) the discovery stage, when mentees develop individual expertise related to their project; (3) the productivity stage, when mentees actively engage in the research experience and collect data; (4) the emergence stage, when mentees become self-directed; and (5) the maturation stage, when mentees extend their scientific pursuits beyond the bounds of their immediate research environment (figures 3 and 4).

Although we present the model as a linear progression, most students do not move through it linearly. The model is

intended as a theoretical framework, not a quantitative binning system. So, for example, a mentee may excel at aspects of stage three, but still be missing components of stage two, and then take on challenges in stage five while still working on accomplishments in stage four. The model is a road map based on the patterns we observed, and should be useful to mentees and mentors as they navigate the scientific training process.

As part of our analysis, we offer solutions to some of the major mentoring challenges we encountered. We also include our thoughts on mentee attrition during the different stages of the research process (figure 4). We use the term attrition to describe students who do not progress to the next stage of development as a scientist, although they may continue to work in research. We note that students who fail to progress with a given project may excel if they change to a new project, research area, laboratory, or mentor. Because inspired science is a pursuit of passion, a good match between student and project is critical for success and retention.

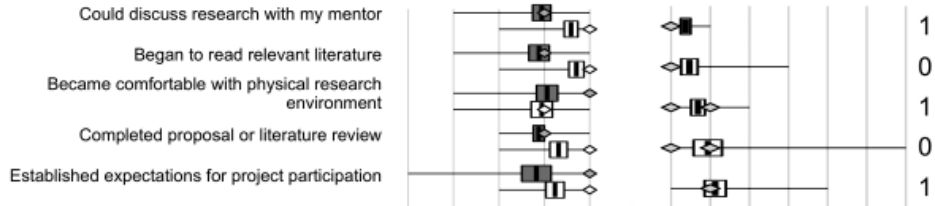
Beginning stage: Initiating a research project

By the end of summer 2008, GATOR undergraduates reported that they felt comfortable in their research environments, had begun to read relevant scientific literature, and could discuss their projects with their mentors (figure 3a). Most had also successfully developed a written research proposal. The proposal, following Sigma Xi guidelines, is a mini-grant assignment in the GATOR program that is internally refereed and funded up to \$500. Mentees were also required to make an oral presentation of proposed work at the end of the summer.

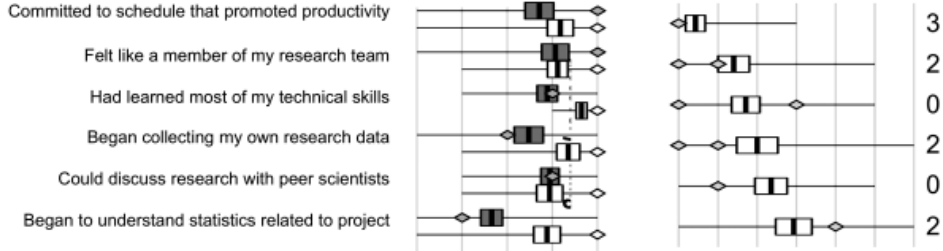
From the mentor’s perspective, the proposal and presentation assignments are valuable because they offer incentives for mentees to assimilate new knowledge into cogent and accessible research plans and allow mentors to assess and constructively critique a mentee’s progress. The value of reading and writing was highlighted by one mentee, who stated: “I...learned to read papers and criticize them. Previously I thought that if it was printed in science books/journals it must be perfectly true. Through GATOR I have learned that studies have limitations and that data can be explained in various ways.”

We observed that the process of initiating a research project actually begins in the interview. In the GATOR program, potential mentees were asked to arrange interviews with potential mentors before submitting their applications. This process mimics the way faculty mentors typically select their graduate students. In their applications, mentees were asked to identify preferred mentors, and mentors selected mentees from this pool. Thus, the interview provided a first opportunity to avoid later attrition caused by a mismatch between mentee and mentor, laboratory, or project. With this in mind, we developed potential questions that proved to be useful in selecting mentees (www.biology.ufl.edu/hhmi/application%20resources.html). In hindsight, several of us recalled emphasizing our excitement about our research while forgoing more selective

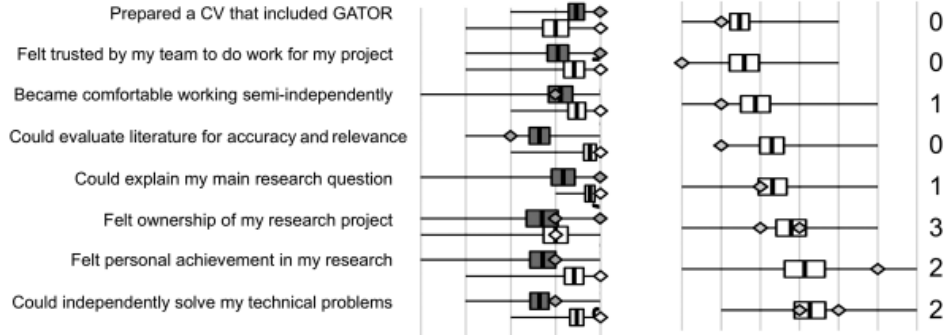
A. Beginning: Initiating a research project



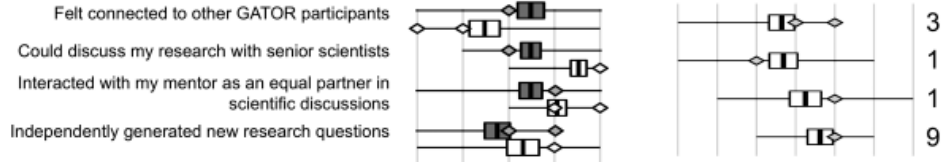
B. Discovery: Developing individual expertise



C. Productivity: Actively engaging the research experience



D. Emergence: Becoming self-directed



E. Maturation: Broader impacts and communication

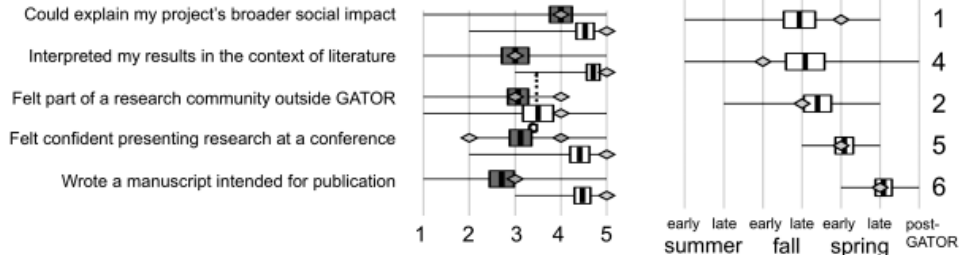


Figure 3. GATOR mentees' (n = 17) responses to 28 internal GATOR survey questions, categorized a posteriori, into five progressive stages of research accomplishment (A–E). Left-hand graphs in each category show how mentees rated their confidence with, and the importance of, specific research skills at the end of the program (confidence = shaded box plots, importance = open box plots). Ratings ranged from very low (1) to very high (5). Right-hand graphs in each category show when mentees reported first encountering each skill during the GATOR program. Data are shown as box plots with a central mean ± 1 standard error; sample modes are depicted as ◇ (there were two modes for some questions). Small variations in the shape of the diamond (◇) are an artifact of sizing the graphs and are not meaningful. Right-hand timing graphs exclude data from students answering “not at all,” indicating that they had not encountered a given skill. Instead, the number of students reporting “not at all” is given to the right of each bar. The x axis labels shown on the bottom graphs are common to all graphs. CV, curriculum vitae.

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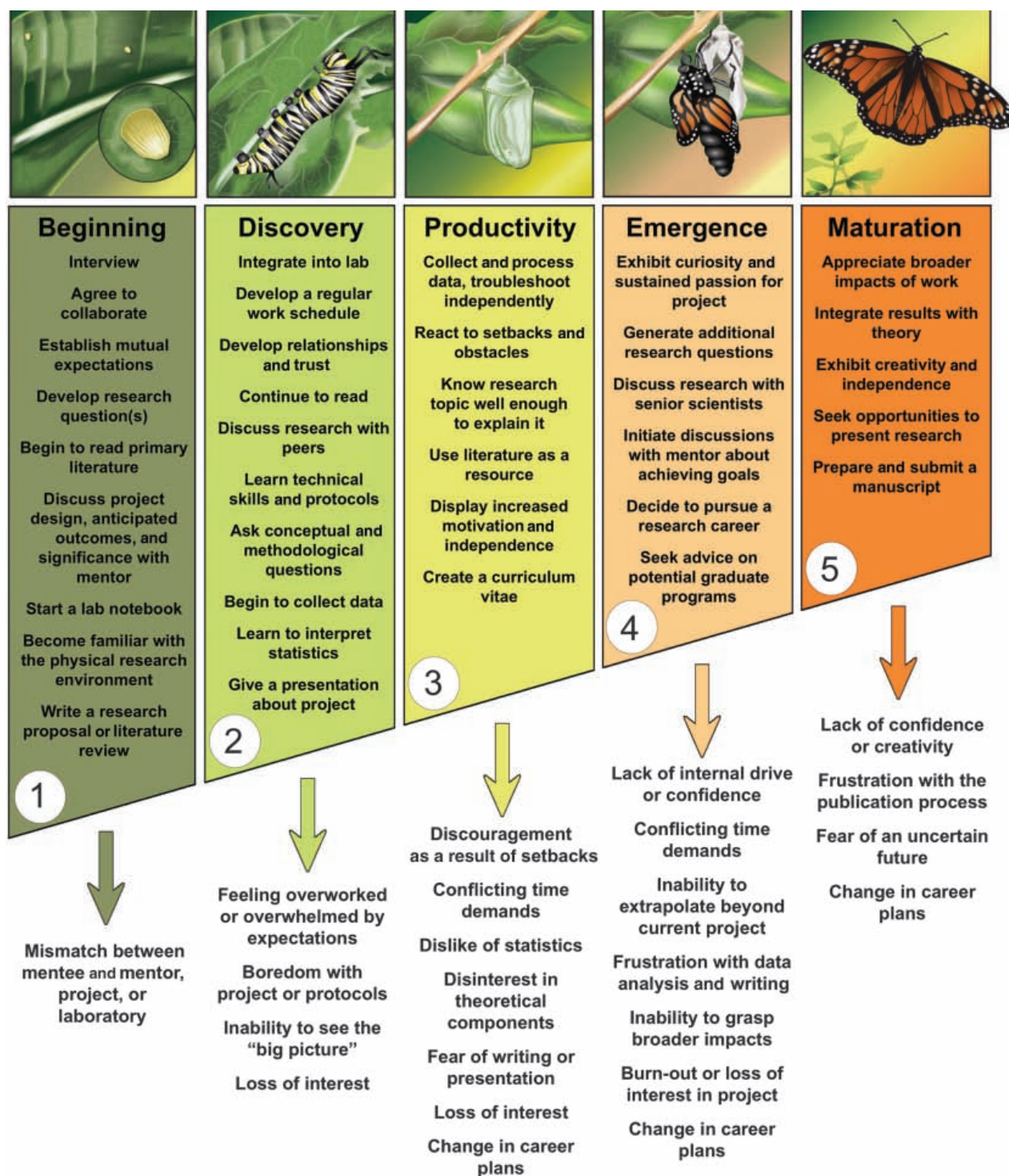


Figure 4. The five-stage Metamorphosis of Mentorship model, developed by examining the progression of undergraduate mentees and their graduate or postdoctoral mentors through the GATOR program. Descriptions of each of the five stages of mentoring are shown in the color panels. Text below the model describes potential reasons for attrition of undergraduates in each stage. In this context, we use the term attrition to describe students who do not progress to the next stage of development as a scientist, although they may continue to work in research. Monarch images: © Neill BioMedical Art and the GATOR program.

questions regarding mutual expectations during interviews. In reality, both enthusiasm and selectivity were needed to identify mentees who would interact productively with the research team.

We also found that it was critical for mentor and mentee to express their expectations early in the experience, as some other mentoring programs have emphasized (Shellito et al. 2001, Millspaugh and Millenbath 2004). Despite this early

programmatically, mentees reported that it took two to three months or longer to establish clear research expectations, with two students reporting that they still had not established clear expectations with their mentors by the end of the GATOR program (figure 3a).

By the end of summer, most mentees had committed to a work schedule that promoted their productivity and they had begun to feel like members of a team (figure 3b). By the fall semester, most had developed necessary technical skills and started collecting data for their projects, although four mentees reported not starting data collection until the spring or later. On average, mentees reported lower confidence with data collection compared with many other skills, and interestingly, two students considered data collection to be of low importance (figure 3b). By mid-fall, most mentees felt confident explaining their research to peers, a skill most rated as important or very important. Of all the skills surveyed, mentees reported the least confidence with their understanding of the statistics related to their research, although the majority of mentees considered this skill important or very important (figure 3b). We placed statistical understanding in the discovery stage because we feel it is part of developing individual expertise, but mentees tended to develop statistical understanding later in the program (fall to spring). This result suggests that mentors need to add statistical interpretation and experimental design to their mentoring curriculum.

We found that teaching a novice mentee during the discovery stage can require significant time investment by the mentor. Support from other mentors was valuable during this stage. It was helpful to communicate boundaries, such as mentor availability and expectations of independent decisionmaking by mentees, early in the mentoring relationship in order to allocate sufficient time for our mentees and our other responsibilities. Teaching technical skills also proceeded more smoothly for mentors who did not attempt to simultaneously learn and teach new protocols.

We observed that attrition among mentees can occur during the steep learning curve associated with developing individual expertise; this failure to progress to the next stage of development as a scientist can occur if the mentee becomes overwhelmed or loses sight of the research objectives. Conversely, an underchallenged mentee can become bored. We found it helpful to provide clear goals and trajectories for achievement while also challenging mentees to take ownership of their projects. We observed that the pace of this stage varied among mentees and that open dialogue and regular mentor-mentee interaction aided progress.

Productivity stage: Active engagement in the research experience

Our survey indicated that most mentees gained confident semi-independence in research during the end of summer or early fall (figure 3c). Most also felt trusted by their research team. By mid-fall, mentees could explain their research, a skill they ranked as highly important (figure 3c). Most

mentees gave a confidence ranking of 3 or 4 to the more advanced skills associated with this stage: evaluating the literature for accuracy and relevance, solving technical problems, and feeling ownership and personal achievement in research. They generally felt that these skills were important or very important and encountered them between fall and early spring (figure 3c).

From the perspective of mentors, challenges during this stage included troubleshooting, maintaining momentum, and responding to setbacks. That said, we observed that most GATOR mentees enjoyed the hands-on process of data collection and a more hands-off approach from their mentors, both of which may be related to the feelings of trust that had developed within research teams. We suggest that this stage, which is focused on data collection and a general feeling of achievement and productivity, typifies what most mentees envisioned when they joined the lab.

However, the danger in this stage is that some mentees perceive data collection as the primary pursuit of scientists. They overlook the theoretical and analytical components of research, underestimate the effort required for data analysis and writing, and fail to develop beyond a “technician” stage of inquiry (Luckie et al. 2004). As a result, we believe that there is an increased risk for passive attrition or stagnation during or immediately following the productivity stage. Mentors can respond to this problem by engaging mentees in intellectual discussions of the research and encouraging them to participate in the scientific community by presenting their data to other scientists.

In addition, during the fall semester, all GATOR participants created curricula vitae. This assignment was valued highly by both mentors and mentees and served as a launching point for a discussion of the credentials needed to fulfill career objectives. Mentees’ realizations that they are building a portfolio of experience through research can promote their sense of autonomy and motivate them to seek further research opportunities. One mentee stated, “I always wanted to attend graduate school, but GATOR gave me the tools necessary to be REALLY prepared to succeed.”

Emergence stage: Becoming self-directed

We characterize emergence as a state of mind that represents a mentee’s personal growth from technician to scientist. Our qualitative observations suggest that emerging mentees exhibit curiosity and sustained passion for their projects and generate their own ideas, questions, and solutions. Such mentees are likely to continue to pursue research careers (McGee and Keller 2007). In addition, they initiate discussions about achieving their career goals and transitioning from their current projects to advanced endeavors, such as graduate school. These mentees also begin to see themselves as colleagues (rather than subordinates) of their mentors and other GATOR participants and appreciate the value of their own scientific contributions. As one mentee commented: “I’ve learned that it takes numerous small achievements to answer one big question. Rarely does one

experiment explain a cause/effect scenario, and that's why it has been difficult for me, someone with grandiose ideas, to appreciate my contribution to the scientific community. [Now, I] see that large strides are made when many scientists make contributions in one area; the problem, mechanism, or solution can be better understood as a whole."

Emergence is a difficult transition to quantify because it represents a philosophical leap that is subjective and variable, depending on the individual. In our group of mentees, 9 of 17 (53%) gave a confidence rating of 4 or 5 to their ability to interact with their mentor as an equal partner in scientific discussions, and 5 of 17 (29%) gave a confidence rating of 4 (none reported a rating of 5) to their ability to generate new research questions. These numbers suggest that, at best, about half of our mentees reached the emergence stage. However, we note that 13 of 17 (76%) mentees reported continued participation in scientific research after GATOR, indicating sustained curiosity and passion for scientific pursuits.

Interestingly, mentees varied widely in the degree of connectedness they felt with other GATOR participants, and they rated this aspect of networking as the least important outcome of their GATOR experience. This contradicts our perspective as mentors: We gained a great deal from our interactions with the other mentors, and with undergraduates from our own and other research teams—including the creation of this manuscript. Our data suggest that undergraduates value their relationships with mentors and senior scientists but less so those with peers (figure 3a, 3d).

Maturation: Broader impacts and communication

By late fall or early spring, mentees could explain the broader social impacts of their research, a skill most rated as important or very important (figure 3e). This progression coincided with a formal group discussion of broader impacts. However, mentees felt less confident in their ability to interpret research findings in the context of the literature, present research at a conference, or write a manuscript, indicating that they needed more time to reach this maturation stage. Most mentees rated maturational skills as important or very important, possibly because we emphasized writing (by asking students to draft a manuscript) and presenting during the spring semester (figure 3e).

GATOR travel funding encouraged conference attendance: 11 of 17 mentees (65%) reported participation in a poster or oral presentation at a regional or national scientific meeting during or shortly after the GATOR program. By the end of the mentoring year, 7 of 17 (41%) of mentees intended to submit a manuscript for publication as a primary author, and another 7 of 17 (41%) were preparing drafts as coauthors. Students who did not have publication plans cited as reasons a lack of data and changing interests.

The skills needed for successful communication of science are different from those used in collecting data; this is one reason that GATOR includes a three-credit course on communicating science during the spring semester. One

of the main assignments is a manuscript-style write-up of GATOR research, a project that students found helpful in getting them started with writing (mean rating of 3.77 ± 0.36 [1 SE] on a scale from 1 [not helpful] to 5 [very helpful]). As with research skills, we found that teaching writing is time consuming and can involve reading multiple drafts of a manuscript. However, it is important because scientific achievement is ultimately measured by one's publication record.

Since the inception of GATOR in 2007, one undergraduate successfully published a first-author manuscript after 20 months in the laboratory. But for the most part, undergraduates, like graduate students, require two to three years to achieve a successful publication, highlighting the importance of targeting lowerclassmen for research mentorship programs. This hypothesis is supported by the observation that undergraduates generally need multiple years of increasingly advanced research experiences to achieve mastery in critical thinking (Henderson et al. 2008). We conclude that the one-year duration and structure of GATOR provided sufficient time for some mentees (but not all) to become invested in their projects and reach the emergence or maturation stages, and that this investment may encourage mentees to pursue publication in the year or two following participation in the program.

Did GATOR promote interest in science careers?

In the GATOR survey (online appendix 1), undergraduate participants reported that GATOR was very helpful in guiding them toward career decisions (mean rating of 4.76 ± 0.14 [1 SE] on a scale from 1 [not helpful] to 5 [very helpful]). Among the GATOR mentees, 8 of 17 (47%) reported that they plan to pursue graduate school and research careers, a decision they made either before GATOR ($n = 4$), or during the summer or fall semesters of the program ($n = 4$). Others were undecided about research (6 of 17, 35%) or decided not to pursue research (3 of 17, 18%) by the end of the program. The decision not to pursue research was typically made during the fall or spring semesters of the program year. Notably, mentees who chose research careers reported greater confidence with being part of a larger research community than did mentees who decided not to pursue research careers (mean confidence scores of 3.4 and 1.5 out of 5, respectively). Although our mentees identified community as one of the least important components of their experience, we posit that a greater emphasis on community may help students achieve the emergence and maturation goals associated with progress in research.

The GATOR experience facilitated additional opportunities for mentees. After the year concluded, 13 of 17 (76%) reported continued participation in scientific research. This number is higher than those who officially chose research careers because it includes students who continued to do research out of personal interest or because it was in an area in which they could gain paid employment, although they did not plan to apply to graduate school. Two undergraduate

mentees secured paid research internships with science research foundations. These outcomes indicate that GATOR supported interest in science careers at a level comparable to other published reports (Russell et al. 2007). As one mentee reflected, "I really enjoyed the program because it shed light on a career path that was particularly enjoyable and agreeable for my personality."

Conversely, mentees in our program who decided not to pursue research careers did so because they (ranked from most to least important, with six mentees responding) found research too time consuming, disliked the challenges of data collection, found the intellectual demands of research unappealing, had financial concerns, found research to be different from what they expected, disliked the cultural or interpersonal dynamics of the research environment, or cited a change in academic or career-related interests. Write-in reasons for deciding against a research career included "realizing that I'd rather gain a wide expanse of knowledge on broad topics than a ton of knowledge on a narrow topic," and "stresses of finding money and being tied down to limited places to work and live."

Did participation in project development affect mentee outcomes?

Other authors have emphasized the benefits of mentee participation in project development, as it promotes a sense of project ownership (Greggerman et al. 1998, Desai et al. 2008). Most GATOR mentees (12 of 17, 71%) participated to some degree in the conceptual development of their projects, although this participation did not predict a mentee's sense of ownership at the end of the research year (linear regression, $p = 0.50$, $r^2 = 0.03$). However, mentees who participated more in project development were more likely to have established expectations for their project ($r^2 = 0.24$) and could better explain their research questions ($r^2 = 0.27$), understand relevant statistics ($r^2 = 0.33$), and generate independent research questions ($r^2 = 0.28$) at the end of the program year (linear regression, $p < 0.05$ for all) than those who were given their projects.

Recommendations and conclusions

As the data above indicate, and in agreement with other published work, undergraduate research experiences are useful and important for aspiring scientists (e.g., Kierniesky 1984, Kardash 2000, Lopatto 2007, Russell et al. 2007). It is generally accepted that undergraduates are better equipped to make career decisions after research experiences, which expose students to both the joys and pitfalls of scientific inquiry.

Based on our observations, we recommend two modifications to typical undergraduate research programs. First, we found the quality of the match between mentor, project, and mentee to be critical for the growth and productivity of the team. Rather than being assigned mentees, as is often the case in summer research programs, especially at large universities, mentors must have the power (and wisdom) to select mentees from a pool of interested and motivated

applicants. Similarly, mentees do best when paired with a project and mentor that they prefer.

Second, the knowledge, technical skills, and relationships needed for meaningful research take time to develop. Our mentees reported an ability to collect data independently and use literature as a resource after four to seven months in the GATOR program. This finding suggests that the summer academic term is not long enough for students to become immersed in meaningful research. Rather, a year of participation is preferred, and even then we observed residual inexperience in several areas. For instance, mentees at the end of the program recognized the importance of critically evaluating and using the literature, collecting research data, solving technical problems, understanding statistics, discussing research with senior scientists, interpreting study results within the context of the literature, and presenting their findings at conferences and in publications. However, they reported (and we observed) residual inexperience and lower confidence in these areas at the end of the year (figure 3). Our data indicate that these skills require additional mentee effort, mentor attention and support, or time to be developed with substantial confidence and effectiveness.

Alternatively, this residual inexperience may indicate that both the mentees and the graduate mentors were undergoing a metamorphosis over the course of the year, resulting in the mentees' perception that they had yet more to learn. Mentoring models in business suggest that mentor proficiency and commitment may influence a mentee's perception of program effectiveness (Allen et al. 2006). The learning process for the mentor may have had the unintended consequence of highlighting how much there is to learn before achieving full autonomy in research for the mentee. It is entirely possible that as a result of working with graduate students, our mentees had a clearer understanding of what they did not know than students who have not observed the intermediate (graduate) levels of academic achievement (Kruger and Dunning 1999). We would like to believe that this heightened perception of the unknown provides mentees with a more realistic view of the scientific process and enhances their preparation for graduate school.

The Metamorphosis of Mentorship model

A number of mentoring models exist in the literature and are focused primarily on the changes in mentoring relationships (e.g., Kram 1983) or on suggested routes toward a successful undergraduate research program (e.g., Millspaugh and Millenbath 2004, Coker and Davies 2006, Henderson et al. 2008). Our model (figure 4) shares many features of traditional mentoring relationships described elsewhere in the literature. Our approach is unique, however, in three ways. First, we attempted to incorporate both the observed changes in the mentoring relationship and the increased scientific sophistication of the mentees into our model. Second, we enumerated when and why mentees were seen to lose interest in a scientific project. Finally, our model

was developed specifically with respect to doctoral student (rather than faculty) mentors. To our knowledge, no other models of graduate student mentorship exist in the literature, despite the prevalence of inexperienced graduate and postdoctoral researchers who function as mentors to undergraduate researchers (see Pfund et al. 2006 for a description of one program's mentor training program).

We developed our model as a road map to the mentoring process, which we anticipate will help mentors predict how mentees will respond to research opportunities (figures 3 and 4). Such predictive mentoring is likely to increase mentor confidence, inform expectations, and facilitate the successful development of mentees. Furthermore, we hope that mentees will use the tangible steps outlined in the road map (figure 4) to navigate their research learning experiences to maximum advantage. Productive two-way mentoring relationships are associated with increased productivity and retention of both mentors and mentees in the science pipeline (Maughan 2001, Steiner et al. 2004, Lopatto 2007, Desai et al. 2008).

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Thea M. Edwards (tedwards@latech.edu) is an assistant professor of biological sciences at Louisiana Tech University, in Ruston, Louisiana. Barbara K. Smith is a postdoctoral fellow with the Department of Physical Therapy, College of Public Health and Health Professions; Danielle L. Watts is a graduate alumni fellow with the School of Natural Resources and Environment; Charlotte C. Germain-Aubrey is a graduate research fellow with the Department of Biology and the Florida Museum of Natural History; and Clayton E. Cox is a graduate research fellow with the School of Natural Resources and Environment; all at the University of Florida, in Gainesville. Alison M. Roark is an assistant professor of biology at Hood College, in Frederick, Maryland. Seth M. Bybee is a postdoctoral fellow with the Department of Biology, at Brigham Young University, in Provo, Utah. Heather J. Hamlin is an assistant professor of obstetrics and gynecology; and Louis J. Guillette Jr. is professor of obstetrics and gynecology, Howard Hughes Medical Institute Professor, and Endowed Chair of Marine Genomics at the South Carolina Center of Economic Excellence, both at the Medical University of South Carolina, in Charleston.