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FEATURE ARTICLE

POINT OF VIEW

Competency-based assessment for the training of PhD students and early-career scientists

Abstract The training of PhD students and early-career scientists is largely an apprenticeship in which the trainee associates with an expert to become an independent scientist. But when is a PhD student ready to graduate, a postdoctoral scholar ready for an independent position, or an early-career scientist ready for advanced responsibilities? Research training by apprenticeship does not uniformly include a framework to assess if the trainee is equipped with the complex knowledge, skills and attitudes required to be a successful scientist in the 21st century. To address this problem, we propose competency-based assessment throughout the continuum of training to evaluate more objectively the development of PhD students and early-career scientists.

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The quality of formal training assessment received by PhD students and early-career scientists (a label that covers recent PhD graduates in a variety of positions, including postdoctoral trainees and research scientists in entry-level positions) is highly variable, and depends on a number of factors: the trainee's supervisor or research adviser; the institution and/or graduate program; and the organization or agency funding the trainee. The European approach, for example, relies more on one final summative assessment (that is, a high stakes evaluation at the conclusion of training, e.g. the dissertation and defense), whereas US doctoral programs rely more on multiple formative assessments (regular formal and informal assessments to evaluate and provide feedback about performance) before the final dissertation defense (***Barnett et al., 2017***). Funding agencies in the US such as the National Science Foundation (NSF) and the National Institutes of Health (NIH) have recently increased expectations for formal training plans for individuals supported by individual or institutional training grants (***NIH, 2012***); but these agencies support only a small fraction of PhD trainees via these funding mechanisms. This variation in the quality and substance of training assessment for PhD students and early-career scientists (***Maki and Borkowski, 2006***) underscores the need for an improved approach to such assessment.

The value of bringing more definition and structure to the training environment has been recognized by professional organizations such as the National Postdoctoral Association, the American Physiological Society/Association of Chairs of Departments of Physiology, and some educational institutions and individual training programs. In addition, a recent NIH Funding Opportunity Announcement places increased emphasis on the development of both research and career skills, with a specific charge that "Funded programs are expected to provide evidence of accomplishing the training objectives". Lists of competencies and skills provide guidelines for training experiences but they are rarely integrated into training assessment plans.

Based on our experience as graduate and postdoctoral program leaders, we recognized the need both to identify core competencies and to develop a process to assess these competencies. To minimize potential confirmation bias we deliberately chose not to begin this project with a detailed comparison of previously described competencies. Each author independently developed a list of competencies based on individual experiences. Initial lists were wide-ranging, and included traditional fundamental research skills (e.g., critical thinking skills, computational and quantitative skills), skills needed for different career pathways, (e.g., teaching skills), and business and management skills (e.g., entrepreneurial skills such as the ability to develop a business or marketing plan). Although we recognize that many of the competencies we initially defined are important in specific careers, from the combined list we defined 10 core competencies essential for every PhD scientist regardless of discipline or career pathway (***Table 1***).

Core competencies and subcompetencies

Broad Conceptual Knowledge of a Scientific Discipline refers to the ability to engage in productive discussion and collaboration with colleagues across a discipline (such as biology, chemistry, or physics).

Deep Knowledge of a Specific Field encompasses the historical context, current state of the art, and relevant experimental approaches for a specific field, such as immunology or nanotechnology.

Critical Thinking Skills focuses on elements of the scientific method, such as designing experiments and interpreting data.

Experimental Skills includes identifying appropriate experimental protocols, designing and executing protocols, troubleshooting, lab safety, and data management.

Computational Skills encompasses relevant statistical analysis methods and informatics literacy.

Collaboration and Team Science Skills includes openness to collaboration, self- and disciplinary awareness, and the ability to integrate information across disciplines.

Responsible Conduct of Research (RCR) and Ethics includes knowledge about and adherence to RCR principles, ethical decision making, moral courage, and integrity.

Communication Skills includes oral and written communication skills as well as communication with different stakeholders.

Leadership and Management Skills includes the ability to formulate a research vision, manage group dynamics and communication, organize and plan, make decisions, solve problems, and manage conflicts.

Survival Skills includes a variety of personal characteristics that sustain science careers, such as motivation, perseverance, and adaptability, as well as participating in professional development activities and networking skills.

Because each core competency is multi-faceted, we defined subcompetencies. For example, we identified four subcompetencies of Critical Thinking Skills: (A) Recognize important questions; (B) Design a single experiment (answer questions, controls, etc.); (C) Interpret data; and (D) Design a research program. Each core competency has between two to seven subcompetencies, resulting in a total of 44 subcompetencies (***Table 1—source data 1***: Core Competencies Assessment Rubric).

Table 1. Ten Core Competencies for the PhD Scientist.

1. Broad Conceptual Knowledge of a Scientific Discipline
2. Deep Knowledge of a Specific Field
3. Critical Thinking Skills
4. Experimental Skills
5. Computational Skills
6. Collaboration and Team Science Skills
7. Responsible Conduct of Research and Ethics
8. Communication Skills
9. Leadership Skills
10. Survival Skills

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The following source data available for Table 1:
Source data 1. Core Competencies Assessment Rubric.
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Assessment milestones

Individual competencies could be assessed using a Likert-type scale (***Likert, 1932***), but such ratings can be very subjective (e.g., "poor" to "excellent", or "never" to "always") if they lack specific descriptive anchors. To maximize the usefulness of a competency-based assessment rubric for PhD student and early-career scientist training in any discipline, we instead defined observable behaviors corresponding to the core competencies that reflect the development of knowledge, skills and attitudes throughout the timeline of training.

We used the "Milestones" framework described by the Accreditation Council for Graduate Medical Education: "Simply defined, a milestone is a significant point in development. For accreditation purposes, the Milestones are competency-based developmental outcomes (e.g., knowledge, skills, attitudes, and performance) that can be demonstrated progressively by residents and fellows from the beginning of their education through graduation to the unsupervised practice of their specialties."

Our overall approach to developing milestones was guided by the Dreyfus and Dreyfus model describing five levels of skill acquisition over time: novice, advanced beginner, competent, proficient and expert (***Dreyfus and Dreyfus, 1986***). As trainees progress through competent to proficient to expert, their perspective matures, their decision making becomes more analytical, and they become fully engaged in the scientific process (***Dreyfus, 2004***). These levels are easily mapped to the continuum of PhD scientist training: beginning PhD student as *novice*, advanced PhD student as *advanced beginner*, PhD graduate as *competent*, early-career scientist (that includes postdoctoral trainees) as *proficient*, and science professional as *expert* (see ***Table 2***).

We therefore defined observable behaviors and outcomes for each subcompetency that would allow a qualified observer, such as a research adviser or job supervisor, to determine if a PhD student or early-career scientist had reached the milestone for their stage of training (***Table 1—source data 1***: Core Competencies Assessment Rubric). A sample for the Critical Thinking Skills core competency is shown in ***Table 3***.

Recommendations for use

We suggest that such a competency-based assessment be used to guide periodic feedback between PhD students or early-career scientists and their mentors or supervisors. It is not meant to be a checklist. Rather than assessing all 44 subcompetencies at the same time, we recommend that subsets of related competencies (e.g., "Broad Conceptual Knowledge of a Scientific Discipline" and "Deep Knowledge of a Specific Field") be considered during any given evaluation period (e.g., month or quarter). Assessors should read across the observable behaviors for each subcompetency from left to right, and score the subcompetency based on the last observable behavior they believe is consistently demonstrated by the person being assessed. Self-assessment and mentor or supervisor ratings may be compared to identify areas of strength and areas that need improvement. Discordant ratings between self-assessment and mentor or supervisor assessment provide opportunities for conversations about areas in which a trainee may be overconfident and need improvement, and areas of strength which the trainee may not recognize and may be less than confident about.

The competencies and accompanying milestones can also be used in a number of other critically important ways. Combined with curricular mapping and program enhancement plans, the competencies and milestones provide a framework for developing program learning objectives and outcomes assessments now commonly required by educational accrediting agencies. Furthermore, setting explicit expectations

Table 2. PhD scientist training stages mapped to Dreyfus and Dreyfus levels of skill acquisition. Early-career scientists include researchers undertaking postdoctoral training as well as those in science positions in career pathways that involve other kinds of advanced training, e.g., on-the-job training or certification.

Dreyfus & Dreyfus	Novice	Advanced beginner	Competent	Proficient	Expert
	Rule-based behavior, limited, inflexible	Incorporates aspects of the situation	Acts consciously from long-term goals and plans	Sees situation as a whole and acts from personal conviction	Has intuitive understanding of situations, zooms in on central aspects
PhD Scientist Training Stages	Beginning PhD Student	Advanced PhD Student	PhD Graduate	Early-Career Scientist	Science Professional

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Table 3. Sample milestones for one of the subcompetencies within Critical Thinking Skills. Verbs in bold font indicate observable behaviors representing each stage of skill acquisition.

	MILESTONES				
CRITICAL THINKING SKILLS	**Beginning PhD Student**	**Advanced PhD Student**	**PhD Graduate**	**Early-Career Scientist**	**Science Professional**
B. Design a single experiment (answer questions, controls, *etc.*)	**Follow** experimental protocols, **seek** help as needed, **describe** critical role of controls	**Plan** experimental protocol; **include** relevant controls; **choose** appropriate methods; **troubleshoot** experimental problems	**Design and execute** hypothesis-based experiments independently; **evaluate** protocols of others; **predict** range of experimental outcomes	Consistently **design and execute** experiments with appropriate controls; **assess** next steps; **critique** experiments of others	**Teach** experimental design; **guide** others doing experiments

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for research training may enhance the ability of institutions to recruit outstanding PhD students or postdoctoral scholars. Finally, funding agencies focused on the individual development of the trainee may use these competencies and assessments as guidelines for effective training programs.

Why should PhD training incorporate a competency-based approach?

Some training programs include formal assessments utilizing markers and standards defined by third parties. Medical students, for example, are expected to meet educational and professional objectives defined by national medical associations and societies.

By contrast, the requirements for completing the PhD are much less clear, defined by the "mastery of specific knowledge and skills" (***Sullivan, 1995***) as assessed by research advisers. The core of the science PhD remains the completion of an original research project, culminating in a dissertation and an oral defense (***Barnett et al., 2017***). PhD students are also generally expected to pass courses and master research skills that are often discipline-specific and not well delineated. Whereas regional accrediting bodies in the US require graduate institutions to have programmatic learning objectives and assessment plans, they do not specify standards for the PhD. Also, there are few – if any – formal requirements and no accrediting bodies for early-career scientist training.

We can and should do better. Our PhD students, postdoctoral scholars, early-career scientists and their supervisors deserve both a more clearly defined set of educational objectives and an approach to assess the completion of these objectives to maximize the potential for future success. A competency-based approach fits well with traditional PhD scientist training, which is not bound by a priori finish dates. It provides a framework to explore systematically and objectively the development of PhD students and early-career scientists, identifying areas of strength as well as areas that need improvement. The assessment rubric can be easily implemented for trainee self-assessment as well as constructive feedback from advisers or supervisors by selecting individual competencies for review at regular intervals. Furthermore, it can be easily extended to include general and specific career and professional training as well.

In its recent report "Graduate STEM education for the 21st Century", ***The National Academies of Sciences, Engineering, and Medicine, 2018*** briefly outlined core competencies for STEM PhDs. In its formal recommendations specifically for STEM PhD education, the first recommendation is, "Universities should verify that every graduate program that they offer provides for these competencies and that students demonstrate that they have achieved them before receiving their doctoral degrees." This assessment rubric provides one way for universities to verify that students have achieved the core competencies of a science PhD.

We look forward to implementing and testing this new approach for assessing doctoral training, as it provides an important avenue for effective communication and a supportive mentor–mentee relationship. This assessment approach can be used for any science discipline, and it has not escaped our notice that it is adaptable to non-science PhD training as well.

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Supplementary Materials for

Competency-Based Assessment for PhD Scientists

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This PDF file includes:

Table S1

Table S1.
Science PhD Core Competencies, Subcompetencies, and Milestones.

1. BROAD CONCEPTUAL KNOWLEDGE OF A SCIENTIFIC DISCIPLINE					
	MILESTONES				
SUBCOMPETENCIES	Beginning PhD Student	Advanced PhD Student	PhD Graduate	Early Career Scientist	Science Professional
A. Knowledge base for multiple disciplines acquired from classes, seminars, journal clubs, etc.	**Discuss**[1] new knowledge	**Respond** to questions demonstrating understanding of new knowledge across disciplinary boundaries	**Formulate** questions that demonstrate understanding of new information and existing knowledge across disciplinary boundaries	**Articulate** connections between new information and existing knowledge across disciplinary boundaries	**Facilitate** discussions across disciplinary boundaries
B. Broad scientific approaches	**Understand** key basic principles and experimental bases for multiple disciplines	**Ask** relevant questions that relate multiple disciplines to research project	**Integrate** multiple disciplines into research	**Participate** in multi-disciplinary research	**Initiate and lead** multi-disciplinary research

2. DEEP KNOWLEDGE OF A SPECIFIC FIELD					
	MILESTONES				
SUBCOMPETENCIES	**Beginning PhD Student**	**Advanced PhD Student**	**PhD Graduate**	**Early Career Scientist**	**Science Professional**
A. Historical context of a specific area	**Describe** major conceptual advances and progressive development of tools and approaches	**Incorporate** historical perspective and **acknowledge** prior contributions in scientific communications.	**Incorporate** historical perspective and **acknowledge** prior contributions in dissertation	**Educate** lab members and others about the historical context	**Review** oral and written scientific communications to ensure that background and significance reflects the historical context
B. Current content expertise in the specific area	**Perform** a literature search; **read, understand, and discuss** primary literature; **attend** seminars	**Recognize** important literature; **ask** seminar speakers relevant questions; **Discuss** key points; **Apply** to doctoral research	**Demonstrate** depth of knowledge by ability to **critically evaluate** papers, **question** dogma, **see** the big picture, **deliver** knowledgeable seminar	**Consistent use** of literature to inform research; quickly **acquire** new knowledge; **add** new information to seminar and collegial discussions	**Articulate** vision of research direction; **demonstrate** independent thinking and creativity; **teach and/or mentor** others
C. Tools and approaches for a specific area	**Use** existing experimental tools and approaches; **seek** help as needed	**Develop** new tools and/or approaches to investigate hypotheses **Develop** a specific aim including hypothesis and experimental approaches	**Demonstrate** comprehensive knowledge of tools and approaches; **Assist** junior lab members in relevant techniques and approaches, both technically and theoretically	**Train** others in the use of relevant techniques and approaches	**Critically analyze** techniques, approaches, and data

3. CRITICAL THINKING SKILLS					
	MILESTONES				
SUBCOMPETENCIES	Beginning PhD Student	Advanced PhD Student	PhD Graduate	Early Career Scientist	Science Professional
A. Recognize important questions	**Describe** background information and **explain** rationale for an hypothesis	**Identify** important questions and hypotheses in a paper or experimental design	**Evaluate** results and **generate** new hypotheses based on historical and current context; **recognize** next important unanswered questions	**Consistently describe** experiments in terms of hypotheses and scientific method; **prioritize** research questions	**Independently generate** new hypotheses, **teach** the scientific method
B. Design a single experiment (answer questions, controls, etc.)	**Follow** experimental protocols, **seek** help as needed, **describe** critical role of controls	**Plan** experimental protocol; **include** relevant controls; **choose** appropriate methods; **troubleshoot** experimental problems	**Design and execute** hypothesis-based experiments independently; **evaluate** protocols of others; **imagine** range of experimental outcomes	Consistently **design and execute** experiments with appropriate controls; **assess** next steps; **critique** experiments of others	**Teach** experimental design; **guide** others doing experiments
C. Interpret data	**Describe** relationship between data and underlying experimental methods	**Understand** experimental methods, **evaluate** data for integrity and validity	Consistently **analyze and interpret** data; **recognize** significant results; **draw** appropriate conclusions	Independently **interpret** data; **use** data to inform experimental design	**Teach** others about data interpretation
D. Design a research program	**Participate** in discussions about research programs; **use** knowledge from literature to **ask** appropriate questions	**Recognize** connections and flow of experiments in a larger project; **explain**	**Design** interrelated experiments to address an overarching question; **make** specific predictions and **define**	**Plan** and **conduct** interrelated experiments needed to build a research program; **use** results to	Independently **design**, **plan** and **direct** a research program; **recognize** significant results and use to **build**

		relationships among results	alternative approaches based on results	identify future research questions	future research programs

4. EXPERIMENTAL SKILLS					
	MILESTONES				
SUBCOMPETENCIES	Beginning PhD Student	Advanced PhD Student	PhD Graduate	Early Career Scientist	Science Professional
A. Identify appropriate experimental protocols	**Understand** how a specific experiment will answer a research question	**Design** experiments following established protocols; include appropriate positive and negative controls	**Explain** the advantages and disadvantages of several relevant protocols to address a specific question	Independently **choose** the most appropriate protocol	**Teach** the selection of appropriate experimental protocols
B. Design and execute experimental protocols	**Observe** and independently **repeat** an existing experimental protocol, preparing necessary reagents	**Execute** an unfamiliar experimental protocol; **demonstrate** procedures; **assist** others with experimental protocols	**Modify** a familiar experimental protocol to meet current needs	**Build** a new protocol using parts of existing techniques to address a novel question	**Create** a novel protocol to answer a previously unanswerable question
C. Identify and troubleshoot technical issues	**Replicate** experimental results; **recognize** when controls indicate technical problems	**Understand** underlying biochemical and technical aspects of protocols to **identify** sources of problems	**Execute** experiments properly based on troubleshooting experience	**Assist** others with troubleshooting techniques	**Teach** troubleshooting techniques
D. Lab safety & regulatory issues	**Complete required training** and **demonstrate** understanding of lab safety & regulatory policies	**Conduct** experiments in compliance with safe laboratory practices and policies	**Help** others follow safe lab practices; **assist** in writing relevant safety & regulatory protocols	**Write** relevant safety & regulatory protocols	**Teach** and **supervise** others about lab safety & regulatory policies

E. Research records and data storage	**Understand** critical nature of accurate record-keeping data security and access; **maintain** intact records of original data	**Understand** confidentiality issues in data; **increase awareness** of issues in research data keeping	**Teach** junior lab members the critical nature of accurate record-keeping data security and access	Supervise junior lab members on appropriate research record keeping; Be a role model	Develop appropriate protocols for storing data; teach accurate record-keeping; help colleagues address issues with data integrity
F. Recognition of data ownership	**Demonstrate understanding** of university policies and professional expectations on data ownership	**Understand** implications of intra- and inter-lab collaboration on data ownership & sharing in scientific and other communications	**Teach** junior lab members about data use and ownership	**Discuss** data ownership with collaborators; **respect** confidentiality and data ownership in peer review	**Proactively address** data ownership issues in an open and fair approach; **help** colleagues address issues with data ownership

5. COMPUTATIONAL SKILLS					
	MILESTONES				
SUBCOMPETENCIES	**Beginning PhD Student**	**Advanced PhD Student**	**PhD Graduate**	**Early Career Scientist**	**Science Professional**
A. Basic Statistical Analysis	**Understand** different data types and how that informs test choice. **Generate** and graph basic summary statistics from original data	**Select appropriate statistical test and design** experimental data collection to support ultimate statistical analysis **in consultation** with statistics expert to ensure proper choices. **Use** appropriate software tools to analyze data	**Independently select appropriate statistical test and design** experimental data collection to support ultimate statistical analysis. **Recognize** when additional statistical consultation is necessary.	**Teach** trainees the value of statistical consultation	**Guide** trainees in choosing appropriate statistical tests and experimental designs in their research field.
B. Bioinformatics Literacy	**Understand** the basics tenets and paradigms of genome biology **including awareness of the complexity of information storage in biological systems.** **Describe** the cross-disciplinary nature of bioinformatics. **Locate** appropriate data repositories	**Recognize when** large-scale data-intensive biological problems are bioinformatics problems; seek expert support to determine appropriate analysis. **Perform** basic data queries in public database.	**Use** appropriate databases, software tools, and algorithms relevant to research projects **Identify** appropriate resources and experts to develop solutions to complex bioinformatics problems.	**Assist** beginning students in the conceptualization of bioinformatics problems.	**Assist** lab members and others in identifying appropriate bioinformatics resources and experts.

6. COLLABORATION & TEAM SCIENCE					
	MILESTONES				
SUBCOMPETENCIES	Beginning PhD Student	Advanced PhD Student	PhD Graduate	Early Career Scientist	Science Professional
A. Openness to collaboration	**Discuss** research effectively within own discipline	**Maintain** an open mind to clearly hear other perspectives; **recognize** that diverse opinions strengthens teams	**Seek help** across disciplines to solve research problems	**Demonstrate** broad intellectual curiosity to ask questions across disciplines	**Collaborate** effectively with colleagues from different disciplines
B. Self-awareness	**Recognize** personal strengths and weaknesses related to discipline-based research	**Recognize** personal strengths and weaknesses related to interdisciplinary research collaboration	**Understand** how own expertise can address a problem and how it differs from contributions of other disciplines	**Recognize** how the contributions of others can address a problem in interdisciplinary collaborations	**Subject** own disciplinary discovery to interpretation and scrutiny by researchers from other disciplines
C. Disciplinary awareness	**Demonstrate** general knowledge of own discipline	**Demonstrate** critical awareness of underlying assumptions of own discipline, its scope and contribution and limitations in addressing a given research question	**Share** research from own area of expertise in language meaningful to an interdisciplinary team	**Engage** colleagues from other disciplines to gain their perspectives on research problems, themes or topics	**Evaluate** the assumptions and limitations of other disciplines in interdisciplinary collaborative initiatives
D. Integration	**Develop** discipline-based research frameworks in collaboration with	**Modify** own research as a result of interactions with	**Develop** interdisciplinary research frameworks in collaboration with	**Integrate** concepts and methods from multiple disciplines in	**Collaborate** with others to integrate theories, methods and insights of multiple disciplines

	other scholars within own discipline	colleagues from other fields	scholars from other disciplines	designing research protocols	
E. Team skills	**Develop** personal team skills in order to strengthen team structure and dynamics	**Understand** strategies for interdisciplinary teamwork and communication including clarifying the meanings of key concepts and appreciating the perspectives of other disciplines	**Build** trust among collaborators in a diverse interdisciplinary team	**Contribute** to the creation of collective interdisciplinary knowledge that includes: thinking with team, adapting individual contributions, trusting value of other contributors, and negotiating differences	**Understand and effectively manage** conflict, feedback and credit relative to interdisciplinary team research

7. RESPONSIBLE CONDUCT OF RESEARCH AND RESEARCH ETHICS					
	MILESTONES				
SUBCOMPETENCIES	**Beginning PhD Student**	**Advanced PhD Student**	**PhD Graduate**	**Early Career Scientist**	**Science Professional**
A. Knowledge about responsible conduct of research (RCR)	**Describe** rules and policies for ethical research practices	**Conduct** research following the rules and policies for ethical research	**Recognize** ethical and unethical research practices	**Teach** or lead discussions about rules and policies for ethical research practices	**Mentor** trainees in RCR
B. Ethical decision making (EDM) in RCR (outcome to process)	**Identify** an ethical question (ethical sensibility: is there an ethical dilemma?); Know procedures for reporting and investigating research misconduct	**Know** one or more moral methods; Respond with correct answer to ethical issues; Understand that there might be multiple “right” answers	**Use** a moral method to address an ethical issue; Know that there are (might be) a plurality of views	**Recognize** ethical issues; Serve as resource or support for trainees confronting ethical issues	**Initiate** and/or lead discussions about how to confront ethical issues
C. Moral Courage	**Understand** that knowing what to do does not equal moral courage	**Seek** help for issues that confront you; **Respond** to hypothetical situations	**Report** unethical practices when encountered; **Recognize** that “authority figures” aren’t always “right”	**Be available** for junior trainees who are facing ethical challenges	**Share** your responses to prior ethical challenges with trainees
D. Integrity	**Know** the importance of character and being honest and fair	**Be conscious** of your own integrity	**Be conscious** of the integrity of those around you	**Be** a role model of integrity for junior trainees	**Be** a role model of integrity for trainees and peers

8. COMMUNICATION SKILLS					
	MILESTONES				
SUBCOMPETENCIES	Beginning PhD Student	Advanced PhD Student	PhD Graduate	Early Career Scientist	Science Professional
A. Informal Oral Presentation Skills	**Introduce** journal article at journal club, including overview of figures; **present** results in laboratory (lab) meeting; **improve** English as a Second Language (ESL) skills (if applicable)	**Discuss** paper in-depth at journal club; **prepare and practice** 2 minute elevator speech on own research to scientists or lay public; **discuss and evaluate** results at lab meeting; **answer** questions about own research spontaneously; **ask** relevant questions at a guest speaker seminar	**Interpret own data and relate** it to research in the field ; **critically analyze** other's research and **fully participate** in lab meeting; **facilitate** thesis committee meeting; **lead** journal club; **apply knowledge to discuss** research with guest scientists and scientists at national meetings; **develop** job interview skills; **improve** ESL skills (if applicable)	**Work** with collaborators; **bring** broader scientific perspective to discussions; **participate in or lead** institutional committee meeting; **mentor** students and junior postdocs on informal presentation skills	**Mentor** junior scientists in developing speaking skills; **deliver** informal scientific talks with and without slides to various audiences; **lead** a group discussion; **participate** in discussions at national/international meetings
B. Formal Oral Presentation Skills	**Deliver** 15 minute oral presentation of thesis project (qualifying/ preliminary exam); **prepare** basic PowerPoint slides with narrative and data	**Present** research at works-in-progress seminar; **prepare** and present complex yet comprehensible ppt slides to describe research	**Present** research at full-length seminars; **deliver** platform presentation at national meetings; **mentor** junior students on presentation skills; **deliver** talk for a job interview, tailored to the audience	**Expertly present** own research in context of others' work; **mentor** students and junior postdocs on formal presentation skills	**Mentor** junior scientists on formal presentation skills**;** **critique** presentations by lab members and colleagues; **develop** experience and proficiency in communication of

					your science and the "big picture."
C. Written Communication - Scientific Manuscript	**Learn** guidelines regarding use of material from publications, including what plagiarism is; **learn** how to properly cite references; **learn** how to abstract material from the literature; **learn** the structure of a scientific publication	**Outline** own research for manuscript; **learn** how to prepare manuscript for particular journal; **analyze** own data and **prepare** figures for manuscript; **learn** how to write introduction and discussion	**Write** literature review and **prepare** manuscript(s) for publication with mentor's help; **draft** response to editors' queries and critiques of submitted manuscripts; **write** thesis, following style guidelines; **show** junior students how to prepare manuscript	**Integrate** own research with broader general scientific context; **participate** in review of laboratory manuscripts; **mentor** students and junior postdocs on manuscript writing; **learn** how to review manuscripts	**Review** manuscripts for publication, including writing constructive critiques; **respond** to critiques appropriately; **mentor** lab members on manuscript writing and review
D. Written Communication - Grant Proposals	**Learn** structure of fellowship proposal; **learn how to write** specific aims; **write** a preliminary/qualifying exam proposal in fellowship or grant format	**Search** for funding opportunities; **learn how to read** a Request For Applications; **write** fellowship application with mentor	**Write** fellowship application independently for review with mentor; **mentor** junior students on finding funding opportunities and grant writing	**Learn how to review** grants; **critique** fellowship applications and grants for others in lab; **develop** specific aims for future independent research	**Review** grants; **sit** on study sections; **communicate** constructive criticisms; respond to critiques appropriately; **mentor** lab members on grant writing and review
E. Written Communication – Meeting Poster	**Distinguish** between slide presentation and poster presentation; **attend** local poster sessions; **participate** in poster preparation	**Prepare** meeting poster with mentor's help; **develop** proficiency at discussing results	**Prepare** meeting poster independently; **discuss** results at poster session; **mentor** junior students on poster preparation	**Design** captivating meeting poster; **listen and evaluate** poster presentation of	**Mentor** lab members on poster presentation; **critique** poster; **listen and critique** practice poster presentation

	by senior lab members	during poster session		junior lab members	
F. Communication with the Public	**Begin to think about** important topics in field of interest and how to present these topics to scientists in other fields and non-scientists	**Design and practice** 2-minute elevator speech to explain research to scientists in other fields and to non-scientists	**Communicate** short and long descriptions of science to variety of lay audiences; **explain** broader context of own research; **participate** in outreach activities to local schools and community groups;	**Lead** outreach activities to local schools, community groups; **mentor** junior lab members on presentation preparation; **participate** in national outreach programs; **learn how to interact** with media professionals	**Interact** with institutional and external media professionals to describe research; **participate** in local and national outreach activities; **provide** scientific expertise as speaker

9. Leadership Skills					
	MILESTONES				
SUBCOMPETENCIES	**Beginning PhD Student**	**Advanced PhD Student**	**PhD Graduate**	**Early Career Scientist**	**Science Professional**
A. Vision	**Articulate** the lab's research direction(s) and their possible role(s) within it	**Explain** own research agenda and role in larger research picture; **beginning to develop** a vision for future career path	**Articulate** future directions of research project and goals for career direction	**Help** junior lab members understand lab's research agenda; **apply** for positions based on research goals and desired career path	**Articulate** overall direction and clear goals to research team and to others via presentations and proposals
B. Integrity	**Learn** institutional and cultural norms of the research community	**Consistently adhere** to rules, regulations, and ethical principles of research conduct; **Is** dependable and trustworthy; **Is** accountable for own actions	**Teach** junior lab members rules, regulations, and ethical principles of research conduct	**Hold** others accountable for their actions	**Model** dependability and trustworthiness; mentors lab members and others on institutional and cultural norms of research community
C. Group dynamics and interpersonal skills	**Contribute** to group/team discussion when prompted; **Learn** about interpersonal relations within the lab and/or institution including cultural diversity	**Contribute** freely to group/team discussions; **Is** respectful of others' ideas; **Is** well prepared for committee meetings	**Coordinate** group efforts to achieve goals given clear guidelines; **Lead** others toward achieving goals; **Assign** tasks by seeking volunteers, delegating as needed	**Listen** actively and **show understanding** by acknowledging and building on others' ideas; **Encourage** others' participation; **Give** recognition	**Involve** group in setting goals; **Organize** group for planning to achieve goals; **Lead** others to work together; Intervenes when tasks are not moving toward goals

				and encouragement	
D. Organization and planning	**Prioritize & coordinate** own tasks within the overall lab program under supervision	**Prioritize & coordinate** own tasks, **integrate** contributions into the overall program with minimal supervision; **effectively manage** time	**Prioritize & coordinate** own tasks, **integrate** contributions into the overall program independently; **Assist** junior lab members with organization and planning skills	**Assist** junior lab members with time and project management	**Prioritize & coordinate** overall research program; **Mentor** junior lab members with time and project management
E. Decision-making	**Voice** opinion when prompted	**Voice** opinion without prompting; **explore** multiple perspectives and **seek** feedback about possible decisions	**Make** responsible and good decisions; **demonstrate** confidence by defending decisions	**Assist** junior lab members with learning decision making process	**Mentor** lab members on decision making skills; **Provide** praise when good decisions are made
F. Problem-solving	**Contribute** information, **brainstorm** solutions, and **assist** in evaluating alternatives when prompted	**Contribute** information, **brainstorm** solutions, **evaluate** alternatives independently; **Build** on others' ideas; **Articulate** problem-solving process	**Offer** insightful or creative solutions, and **provide** a framework for evaluating alternatives; **assist** junior lab members with problem solving process	**Solve** own problems with minimal assistance; **support** lab members with problem-solving process	**Lead and educate** research team on problem-solving process; **evaluate** and **select** most effective approach to solve problems; **collaborate** with others on problem-solving
G. Managing Conflicts	**Learn** to work effectively with others: **recognize**	**Learn** to mediate conflict situations by	**Participate in** conflict resolution and **guide** others to a	**Resolve** conflict based upon objective criteria	**Mentor** others in difficult situations

	conflicts, **seek** advice in difficult situations to avoid escalation	emphasizing goals / issues rather than personalities; **Offer** solutions; **Maintain** collegiality	collegial research environment	and varied approaches	and conflict resolution

10. Survival Skills					
	MILESTONES				
SUBCOMPETENCIES	Beginning PhD Student	Advanced PhD Student	PhD Graduate	Early Career Scientist	Science Professional
A. Motivation	**Accept direction** passively; **attend** required scientific functions when prompted	**Attend** required scientific functions without being prompted; **Display curiosity** about science via discussion	Self-driven for planning and direction; **attend** required and elective scientific functions of value to training; **display passion** for science; **share excitement** for science with others	Actions reflect goals beyond what is required; **proactive** in problem-solving and decision-making; **influence** events to reach goals	Spontaneously take advantage of opportunities; **role model** for self-motivation, and able to **mentor** others
B. Perseverance	**Complete first-year curriculum** in the face of the unique pressures and demands of graduate school and research	Willingly **repeat experiments** as needed to find answers; begin to **develop** alternative strategies to overcome obstacles	**Complete** dissertation research in the face of continued pressures and demands; **Engage** others for support; **assist** junior lab members with coping mechanisms for pressures and demands	**Educate** junior lab members on the pressures and demands and coping mechanisms; play a junior **mentoring** role	**Mentor** others on coping mechanisms for pressures and demands; continue active career in biomedical science
C. Adaptability	**Adapt** to graduate-level coursework; **Manage** complex schedule of classes, rotation research, and other time demands	**Change priorities** to meet varying demands; **adjust approach** to match varied task requirements	**Adjust own behavior** to work with others and adapt to new situation	**Adjust** quickly to new responsibilities and tasks; **assist** junior lab members to adapt to new situations	**Adapt** effectively to varying responsibilities & tasks; **mentor** others to adapt to new situations
D. Professional Development	**Attend** required professional and/or career development	**Use** Individual Development Plan (IDP)	Has **awareness** of research organization and roles within it;	**Aware** of own professional development	**Seek** continuing professional development

	courses or seminars; Becoming **self-aware** of development as a scientist	appropriate to stage of training	**seek** additional opportunities for professional development relevant to desired career pathways	needs for desired career pathway; **use** Individual Development Plan (IDP) appropriate to stage of training	opportunities for self-improvement; **mentor** others about professional and career development
E. Networking	**Get to know** peers. **Meet** faculty.	**Get to know** members of your thesis committee and other faculty	**Talk** with scientists at national meetings about both your research and their research	**Identify and communicate** with potential future colleagues / co-workers.	**Identify and develop** relationships with collaborators.

[1]Verbs in bold font indicate observable behaviors representing each stage of skill acquisition.