

# Using Rubrics to Evaluate Graduate Applications

## **Module Description and Intentions**

This module is intended for a group of 3-5 faculty to complete all activities in approximately 90-minutes. Faculty will reflect on their current admissions practices through the discussion of relevant research and the collective development and application of a rubric.

We provide an overview of several categories to consider including within a rubric for graduate admissions. However, we intend for faculty to use this module to take a deep dive into a single category (academic preparation) to serve as a foundation that they can continue to build upon with the inclusion of other suggested categories in the future.

Finally, as part of the activities in this module, we provide sample pieces of a graduate application (transcript, letter of recommendation, etc.). However, based on our in person facilitations of this module, we strongly recommend pre-selecting 1-2 graduate applications from previous admissions cycles in your program. Applications from students who were on the borderline are the most optimal because they will likely contain the nuance and subjectivity rubrics are designed to assess.

## Using Rubrics To Evaluate Graduate Applications

Read the information in the document and work through the activities either individually (for self-study) or with a group of 3-5 people (intended implementation).

### Learning Objectives

By the end of this module your group will:

- Engage in discussion regarding what categories should be included and on a rubric of academic preparation for evaluating incoming graduate students.
- Develop a rubric on Academic Preparation including the operationalization of quality levels (high, medium, and low).
- Use a sample rubric to rigorously evaluate several elements of a graduate application (including personal statements, a letter of recommendation, and an interview) for qualities that you are looking for in potential graduate students.

### Activity: Rubric Preconceptions

1. In your opinion, compared to your current practice of evaluating applications, how will using a rubric to assess all submitted applications will affect the following...

The efficiency of the review	<i>Increase</i>	<i>Not affect</i>	<i>Lower</i>	<i>Unsure</i>
The quality of the review	<i>Increase</i>	<i>Not affect</i>	<i>Lower</i>	<i>Unsure</i>
The fairness of the review	<i>Increase</i>	<i>Not affect</i>	<i>Lower</i>	<i>Unsure</i>



Discuss Question 1 as a group.

This module is designed to help you design a rubric that evaluates criteria that your program values in a robust way to help mitigate the influence of implicit biases, and increasing fairness. Since all members of the admissions committee will be developing and applying a rubric that specifically addresses what your program values, the process becomes more efficient since reviews are more targeted on comparing the same criteria across multiple applicants. Finally, using rubrics allows reviews to look at the whole applicant instead of a single feature of the application, increasing the quality of the review.

There are many ways of looking at rubrics, each with its own set of pros and cons. We have opted to take the approach of having you get firsthand experience in the creation of a piece of a rubric, but then focus more on using a rubric as a means to evaluate graduate applications.

### Section 1: Overview of Rubrics

Benefits of rubrics include:

- Providing a consistent structure for comparing all applications on multiple dimensions

- Increasing efficiency of the review process
- Reducing implicit bias
- Increasing reliability across reviewers
- Increasing transparency about the evaluation process

In this module, each of these benefits will be discussed.

### Anatomy of a Rubric

Rubrics can be used to evaluate students' applications with predefined and well-articulated criteria:<sup>1</sup>

- **Categories** – categorical themes that provide a comprehensive assessment of the candidate's portfolio and are made up of clusters of Criteria
- **Evaluative Criteria** – detailed criteria to be assessed; clusters of these comprise the Categories; criteria are defined with Score Descriptions
- **Quality Criteria** – coarse grained **scoring levels** (e.g., high, medium, low)

*Category*

*Scoring Level*

#### Research Potential and Experience

Criteria	High	Medium	Low
variety/duration	At least two academic years in research	One to two academic years in research	Less than one academic year in research
technical skills	A variety of experimental, theoretical, and/or computational research skills	Has developed only one class of skill (exp or theory or comp)	Demonstrated little more than skills necessary for coursework
attitude toward research	Clear commitment to and enthusiasm for research, from all available evidence	Commitment to or enthusiasm for research, from more than one piece of evidence	Commitment to or enthusiasm for research unclear or only evident from personal statement
clarity of interests	Student has specific interests, is clear about details, and expresses an understanding of the big picture implications	Student can state interests, but they are general or superficial	The student does not have clearly stated interests

*Evaluative Criteria*

*Quality Criteria*

<sup>1</sup> Reddy and Andrade (2010)

## Rubrics Increase Efficiency

Even without keeping documentation of each review, evaluating over 200 applications is very time-consuming. Using rubrics can help minimize the time spent evaluating, increase transparency of application decisions, and address concerns about equity and fairness<sup>2</sup>.

Issue	How Rubrics Address Issue
Evaluation is tedious and time-consuming	Rubrics can speed up the process of evaluating applications because the scoring levels for the criteria have already been defined and are not having to be arbitrarily justified for each applicant.
Transparency	Rubrics highlight precisely where the applicant lost points, removing the need for extensive conversations about why points were awarded/lost.
Concerns about equity and fairness	Rubrics use established criteria to allow for a more consistent evaluation of applicants. This process improves fairness in the evaluation because they prevent mid-evaluation changes in criteria. Finally, rubrics ensure that applications are reviewed in their entirety.

## Rubrics Provide Structure and Reduce Bias

Rubrics give structure to observations. Matching your observations of a student's application to the descriptions in the rubric averts the rush to judgment that can occur, especially in time-sensitive evaluation situations. Instead of *judging* the performance, the rubric *describes* the performance. The resulting judgment of quality based on a rubric also contains a description of performance that can be used for feedback (if needed). This is different from a judgment of quality from a score, or a grade arrived at without a rubric.<sup>3</sup>

There is extensive literature on inconsistency in grading bias in grading.

*Example 1:* Female 12th grade students whose primary language is English earn statistically significant higher grades than all other students, even when holding test scores and student, teacher, school, and district characteristics constant.<sup>4</sup>

<sup>2</sup> Stover (2017)

\*Rubric terminology as seen in the literature

<sup>3</sup> Brookhard (2013)

<sup>4</sup> Rauschenberg (2014)

*Example 2:* There can also be inconsistency in the grader themselves. “An essay that earns a B at one moment might earn an A the next day. It shouldn’t be that way, but an honest teacher will admit that it’s true.”<sup>5</sup>

*Example 3:* Grading criteria can sometimes be internalized. When this occurs, raters are sometimes unable to verbalize the criteria used and default to citing a ‘gut feeling’. Often, these ‘gut feelings’ are influenced by the raters’ preexisting bias resulting in transparency, validity and reliability being problematic.<sup>6</sup>

### **Rubrics Increase Transparency**

Rubrics provide evidence that support application decisions. This may be useful in heading off charges of unfairness by faculty whose individually preferred applicants may have been denied admission, or by applicants that may feel aggrieved by the program’s decision.

Providing prospective students with criteria before submission of their application can (1) help clarify what is expected within their personal statements, and (2) “level the playing field” for students. This in turn leads to better applications because students can be more explicit about criteria that faculty have chosen for their rubrics.

### **Rubrics Enhance Interrater Reliability**

Rubrics improve rater reliability<sup>7,8,9</sup> and are particularly useful for assessing large cohorts and for situations where multiple faculty members are working together to assess elements for which there is shared expertise. For example, all the faculty evaluating applications have shared expertise in evaluating academic preparation criteria such as GPA. There may also be certain criteria for which assigning a subset of the faculty to assess is more appropriate, such as technical research skills.

When using rubrics it is a best practice to do some “norming” prior to each application season. This practice can be as simple as reviewing an application or two from the previous year using the rubric. This process is intended to build a rater’s internal consistency with how they are determining score levels. It is okay if multiple raters score applicants differently on a few of the rubric criteria as there will always be some level of subjectivity and interpretation; however, major discrepancies between raters should always be discussed!

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<sup>5</sup> Tierny (2013)

<sup>6</sup> Svennberg, Meckbach, and Redelius (2014)

<sup>7</sup> Oakleaf (2009)

<sup>8</sup> Thaler, Kazemi, and Huscher (2009)

<sup>9</sup> Crotwell Timmerman, Strickland, Johnson, and Payne (2011)

## Evaluating Text

The process of evaluating narrative text has four steps:

1. Making a rubric
2. Evaluating text
3. Assigning a quality level
4. Discussing any discrepancies

These steps drive the next two sections of the module wherein you will design your own rubric and then use it to critically evaluate a graduate application.

## Section 2: Designing A Rubric

This section is going to guide you through the creation of an Academic Preparation rubric. We specifically chose this category based on interviews with faculty who stated that academic preparation was very important to them when evaluating graduate applications. Then, you will use the rubric you have created to evaluate an academic transcript.



We have provided pieces of a sample graduate application that can be used in this module; however, if you were able to bring 1-3 sample applications from your own program, we strongly recommend that you use those instead.

### Activity: Designing a Rubric: Criteria

2. Using the table below – fill in the following table. We recommend having no more than four pieces in order to avoid making the rubric too cognitively complex; though, fewer than four might be sufficient for your program.

What pieces of <i>Academic Preparation</i> are important to you and/or your program?	How do you measure those pieces?

Each of the items in the first column of the table above correspond to the **Evaluative Criteria** in your rubric. In the next activity, you will use the information about how to measure each of those **Evaluative Criteria** to determine the **Quality Criteria** for each level.

**Rubrics: Score Descriptions**

Once the Criteria have been determined, the next step is to articulate the descriptions that correspond with each scoring level. The following is a *bad* example of descriptors used to measure applicants Publication and Presentation records.

<b>Criteria</b>	<b>High</b>	<b>Medium</b>	<b>Low</b>
<b>Publications and Presentations</b>	<i>First-author on a refereed publication AND Invited oral presentation of original research at a professional science-focused conference</i>	<i>Co-author on a refereed publication AND Contributed oral presentation of original research at a professional science-focused conference</i>	<i>No referred publications OR Poster presentation of original research at a professional science-focused conference</i>

**Red Flag 1:** There are some very plausible situations that are not represented by any of the description levels. For example, students who have presented a poster at a conference and have been a co-author on a paper do not clearly fall into one category. There is too much of a gap between the levels.

**Red Flag 2:** In looking at the descriptions in the rubric above, it becomes apparent that each level will not comprise approximately 33% of graduate school applicants in physics. Very few students will be classified as “High” with the requirements of being the first author on a refereed publication and having been invited to give a talk at a conference. Conversely, the majority of students will likely fall into the Low category.

When articulating descriptions, there should be an approximately even division of students at each scoring level.<sup>10</sup> In the rubric below there will likely be a more even categorization of students in each scoring level.

<b>Sub-Criteria</b>	<b>High</b>	<b>Medium</b>	<b>Low</b>
<b>Publications and Presentations</b>	Contributions consistent with the level of co-author or first-author on a refereed publication AND Presented original research at a professional science-focused conference	Contributions consistent with the level of a co-author on a refereed publication OR Presented original research at a professional science-focused conference	Level of a student-focused/regional conference OR co-author of unrefered pub

<sup>10</sup> Janssen, Meier, and Trace (2015)

**Bifurcation for Program Needs**

Graduate programs often have faculty engaged in multiple areas of research. The ideal graduate student for a researcher who does computational astrophysics may need to be well versed in programming languages such as Python and C, but perhaps does not require as much of a theoretical mathematics background. On the other hand, the ideal graduate student for a professor studying quantum field theory would be one who has completed advanced math courses and may not be so concerned at their current level of programming skills.

There can be different rubrics depending on the needs of the department, or, specific **Evaluative Criteria** can be weighted more than others, depending on program needs.

**Activity: Designing a Rubric: Descriptions**

3. Using the rubric below, fill in your Evaluative Criteria from Question 2. As a group, articulate your descriptions for each of the scoring levels in the rubric table below. Think about what it means for an applicant to be high, medium, or low on each of these. The more concrete your definitions, the more consistent you can expect your judgments to be. Again, you may have fewer than four evaluative criteria here, but we recommend no more than four. The Transcript column will be used in the next activity.

**Academic Preparation**

Evaluative Criteria	High	Medium	Low	Transcript
				<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low
				<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low
				<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low
				<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low

**Activity: Using a Rubric: Sample Academic Transcript**

4. Using the Transcript column in the Academic Preparation rubric that you just created, *individually* evaluate either:

- the sample transcript from a student’s application found in Appendix A.
- 1-3 transcripts from your past applicants





Once you have completed the activity, *as a group* discuss how each of you scored the transcript(s). Then, reflect on the following questions:

- Did anything in your rubric need to be adjusted after evaluating sample transcripts?
- Were all raters in agreement? If not, were those discrepancies due to individual subjectivity (which is part of the process) or due to unclear quality level descriptions?

**Moving Forward:**

We encourage you to repeat the activities in Section 2 with other categories that you want to include in your rubric. Some examples include: Research Potential and Experience, Alignment with Mission and Expertise, Non-Cognitive Competencies, and Diversity Contributions.

**Section 3: Applying a Rubric**

In this section we are going to switch focus from developing a rubric to applying one. As your group has likely experienced in Section 2, the development of a rubric takes time. For this next section, we will provide you with a sample rubric that you can use to evaluate the more subjective pieces of a graduate application. Though our sample has four criteria, if your group collectively decides that one or more of the criteria are not relevant to your program, feel free to cross out that row in the rubric.

We acknowledge that there is always some level of interpretation that comes with using a rubric. The goal is not for complete uniformity among raters, but to be more systematic in the evaluation process with more emphasis on justification rather than a pure reliance on “gut feelings.”

**Activity: Using a Rubric: Sample Personal Statement**

5. Using the sample rubric below for Research Potential and Experience, *individually* evaluate either:

- the sample personal statement from a student’s application found in Appendix B.
- 1-3 personal statements from your past applicants



Once you have completed the activity, *as a group* discuss how each of you scored the personal statement(s).

**Research Potential and Experience**

Criteria	High	Medium	Low	Personal Statement
Variety and Duration	At least two academic years in research	One to two academic years in research	Less than one academic year in research	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low

<b>Technical Skills</b>	A variety of experimental, theoretical, and/or computational research skills	Has developed only one class of skill (exp or theory or comp)	Demonstrated little more than skills necessary for coursework	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low
<b>Attitude Towards Research</b>	Clear commitment to and enthusiasm for research, from all available evidence	Commitment to or enthusiasm for research, from more than one piece of evidence	Commitment to or enthusiasm for research unclear or only evident from personal statement	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low
<b>Clarity of Interests</b>	Student has specific interests, is clear about details	student can state interests, but they are general or superficial	Student does not have clearly stated interests	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low

**Activity: Using a Rubric: Sample Letter of Recommendation**

6. Using the sample rubric below for Research Potential and Experience, *individually* evaluate either:

- the sample letter of recommendation from a student’s application found in Appendix C.
- 1-3 letters of recommendation from your past applicants



Once you have completed the activity, *as a group* discuss how each of you scored the letters of recommendation.

**Research Potential and Experience**

Criteria	High	Medium	Low	Letter of Recommendation
<b>Variety and Duration</b>	At least two academic years in research	One to two academic years in research	Less than one academic year in research	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low
<b>Technical Skills</b>	A variety of experimental, theoretical, and/or computational research skills	Has developed only one class of skill (exp or theory or comp)	Demonstrated little more than skills necessary for coursework	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low
<b>Attitude Towards Research</b>	Clear commitment to and enthusiasm for research, from all available evidence	Commitment to or enthusiasm for research, from more than one piece of evidence	Commitment to or enthusiasm for research unclear or only evident from personal statement	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low

<b>Clarity of Interests</b>	Student has specific interests, is clear about details	student can state interests, but they are general or superficial	Student does not have clearly stated interests	<ul style="list-style-type: none"><li>○ High</li><li>○ Medium</li><li>○ Low</li></ul>
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**Optional Activity: Using a Rubric: Interviews**

7. This activity is optional and requires that an interview video or transcript be available to use from a past applicant in your program. More graduate programs have begun incorporating interviews as part of the application process (especially during COVID-19). Using the sample rubric below for Research Potential and Experience, *individually* evaluate either:

- 1-3 interviews from your past applicants



Once you have completed the activity, *as a group* discuss how each of you scored the interviews.

**Research Potential and Experience**

Criteria	High	Medium	Low	Interview
<b>Variety and Duration</b>	At least two academic years in research	One to two academic years in research	Less than one academic year in research	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low
<b>Technical Skills</b>	A variety of experimental, theoretical, and/or computational research skills	Has developed only one class of skill (exp or theory or comp)	Demonstrated little more than skills necessary for coursework	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low
<b>Attitude Towards Research</b>	Clear commitment to and enthusiasm for research, from all available evidence	Commitment to or enthusiasm for research, from more than one piece of evidence	Commitment to or enthusiasm for research unclear or only evident from personal statement	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low
<b>Clarity of Interests</b>	Student has specific interests, is clear about details	student can state interests, but they are general or superficial	Student does not have clearly stated interests	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low

## Connecting the Rubric Pieces

When evaluating a potential student, there will be evidence of research potential and experience in each piece of the application. Bringing all of these pieces together allows for a big picture view of each category.

### Research Potential and Experience

Criteria	High	Medium	Low	Academic Transcript	Personal Statement	Letter of Recommendation	Interview
<b>Variety and Duration</b>	At least two academic years in research	One to two academic years in research	Less than one academic year in research	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low
<b>Technical Skills</b>	A variety of experimental, theoretical, and/or computational research skills	Has developed only one class of skill (exp or theory or comp)	Demonstrated little more than skills necessary for coursework	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low
<b>Attitude Towards Research</b>	Clear commitment to and enthusiasm for research, from all available evidence	Commitment to or enthusiasm for research, from more than one piece of evidence	Commitment to or enthusiasm for research unclear or only evident from personal statement	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low
<b>Clarity of Interests</b>	Student has specific interests, is clear about details	Student can state interests, but they are general or superficial	Student does not have clearly stated interests	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low	<input type="radio"/> High <input type="radio"/> Medium <input type="radio"/> Low

Finally, using a rubric to evaluate personal statements usually requires 2-3 repetitions to master the learning curve. Practicing evaluating old applications with the developed rubrics will allow for those norming conversations to occur before the start of the application cycle. A rubric is a living document, continue discussions with colleges to update rubrics as needed after the completion of each application cycle.

## Moving Forward

At the completion of this module, you have:

- Engaged in discussion regarding what categories should be included on a rubric of academic preparation for evaluating incoming graduate students.
- Developed a rubric on Academic Preparation including the operationalization of quality levels (high, medium, and low).
- Used a sample rubric to rigorously evaluate several elements of a graduate application, including personal statements, a letter of recommendation, and an interview.

Now, we invite you to take these tools and skills further by continuing the development of your rubric by operationalizing quality levels for other categories. Then, to test the efficacy of your rubric before using it in an admissions cycle, we suggest admissions committee members practice evaluating on small selection of applications from previous years. A practice cycle will allow faculty to get acquainted with the practice of using more rigorous evaluation to evaluate subjective (and often imperfect) applications in an effort to avoid relying purely on “gut feelings.”

## References

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## Appendix A Academic Transcript

**Name: Jane Smith**

**University ID: 0000000001**

Plan: Bachelor of Science in Physics

2016-11-17: Active in Program

Program: UGRD Science

Plan: Bachelor of Science in Physics

<b>Fall 2015</b>		
ACSC 10	Freshman Seminar	Pass
CHMG 141	General & Analytical Chemistry I	B
CHMG 145	General & Analytical Chemistry I Lab	A
MATH 182	Project-Based Calculus II	C-
PHYS 150	Introduction to Special Relativity	C
PHYS 216	University Physics I for Physics Major	C+
<b>Spring 2015</b>		
CHMG 142	General & Analytical Chemistry II	C-
CHMG 146	General & Analytical Chemistry II Lab	A-
ITDS 359	STEM Education: Research & Practice	A
MATH 221	Multivariable & Vector Calculus	D
PHYS 217	University Physics II for Physics Majors	D
<b>Fall 2016</b>		
COMM 201	Public Speaking	A
MATH 231	Differential Equations	C
MATH 251	Probability and Statistics	W
PHYS 213	Modern Physics	C+
PHYS 225	Introduction to Computation Physics & Programming	B-
PHYS 275	Sophomore Physics Seminar	C+
<b>Spring 2016</b>		
COMM 211	Principles of Advertising	A
ENGL 345	History of Madness	A-
MATH 241	Linear Algebra	B-
PHYS 220	University Astronomy	C+
PHYS 222	Electronic Measurements	C+
PHYS 283	Vibrations and Waves	B
<b>Fall 2017</b>		
COMM 202	Mass Communications	A-
PHYS 214	Modern Physics II	B-
PHYS 315	Experiments in Modern Physics	C
PHYS 320	Math Methods in Physics	C
PHYS 330	Classical Mechanics	A-
<b>Spring 2017</b>		
COMM 253	Communication	A
COMM 305	Persuasion	B+
PHYS 295	Physics Research	A
PHYS 316	Advanced Laboratory in Physics	B
PHYS 411	Electricity and Magnetism	C



PHYS 450	Capstone Preparation	A
<b>Fall 2018</b>		
PHYS 412	Advanced Electricity & Magnetism	A-
PHYS 414	Quantum Mechanics	B-
PHYS 440	Thermal & Statistical Physics	B
PHYS 451	Capstone Project I	A
SOCI 315	Global Exiles of War & Terror	A

**Undergraduate Career Totals**

Cumulative Credit Hours Attempted	113.000
Cumulative Credit Hours Earned	95.000
Cumulative Credit Hours GPA Units	95.000
Cumulative Credit Hours Points	257.670
 Cumulative GPA	 2.710

## Appendix B

### Personal Statement

How many stars are in a solar system?

This question might cause one to pause, and wonder why a scientist would pose such an obvious inquiry. For astronomers, the answer is usually obvious on first pass, but understanding how a solar system, or other star system, came to be is a more taxing undertaking. For students, however, the answer to this question might get confused with Carl Sagan's voice saying "billions and billions" and lead to some disoriented introductory astronomy students. My research interests, as well as my long-term career goals involve the synthesis of astronomy research and astronomy *education* research. For a full understanding of one, the other must also be well-understood. I intend to use my growing set of research skills to study both topics during my time as a graduate student, and attending your school would allow me to complete projects that span more than one research field.

Solar system formation is a topic that we should be interested in understanding as humans. It is innate to wonder where we came from and how everything happened ever so precisely to land us here on the only known habitable planet. Up until somewhat recently, there was only one single solar system to study in detail – ours. However, with better instruments and a more concrete understanding of the evidence that points to planetary systems around stars, we can now engage in studies of more than our own system. We can also study other types of star systems, like binary star systems, and ultimately gain a better understanding of how stars interact with objects around them, and what sort of implications that might have for various systems. I am a young scientist with an improving research background, and I wish to study these systems.

My research background is quite well-rounded, which will be beneficial to completing the research projects described. During my undergraduate career I spent two summers engaged in research at the National Radio Astronomy Observatory (NRAO) involving megamaser observations. Under the supervision of Dr. John Smith at the NRAO I completed several weeks of independent research in which I refined existing computer code and created original code to look for megamaser detections in a large survey of data. The data were combined and the noise of the observations was removed in search of low-signal megamaser activity not discernable on an individual scale. This project culminated in a poster presentation at the American Astronomical Society's 229<sup>th</sup> meeting. During this time, while I was not working on stellar system research, I developed an appreciation for astronomical research in general after seeing it first-hand. The experience allowed me to complete an individual research project with guidance from an expert in the field, which showed me that I perform my best under such conditions. When I can

take time to grapple with and understand material on my own, and then receive support and advisement from an advisor, my understanding of my project and my productivity increase.

I noticed this feeling again during my final year in college. I worked on an independent research project under the expertise of a physics professor, this time focused on physics education research rather than astronomy or physics research. My advisor and I worked together to establish a solid research question and plan. Then I completed the remainder of the project independently. I developed a survey that was used in tandem with a standardized physics test to study self-efficacy in two student populations: non-physics majors and prospective physics majors. This semester of research culminated in a final research paper entitled, “Self-Efficacy, Identity, and Physics: How Separating Non-Majors and Prospective Majors Affects Performance in Fundamental Physics II.”

Unlike the NRAO research, I felt that my findings from the education research touched many more minds. While megamaser research is interesting and certainly important for a well-rounded understanding of galaxies, the physics education research immediately impacted how the professor taught. The professor noted, in detail, after the completion of my project that she now had many changes to make to her classroom and several new perspectives to take into consideration during her daily teaching routine. To me, a very relevant question still within physics and astronomy is how students learn their physics and astronomy content.

In addition to these research experiences, I have also worked to teach science to a wide age-range of students (as young as pre-kindergarten up to high school) and feel that my experience in the classroom increases my strengths to study both astronomy and education. Combining physical science research with social science research is important as nothing can be done in a vacuum. All scientists, students, and members of society carry their misconceptions with them and can ultimately lead to frustration and abandonment of the science field. My diverse background in both astronomy research and applied physics education research are evidence that I can perform well while engaging with unanswered questions, in two related fields.

My career goals include the ability to study both astronomy and astronomy education long-term. I will be an expert in both fields and will be able to immerse myself in research projects that answer questions about how astronomical phenomena come to be and how students understand them. The financial demands of completing two (albeit related) projects during graduate school are great and attending your school would allow me to be fully invested in research questions that might otherwise be less relevant to my future goals.

Scientific research cannot happen in a vacuum. Each perspective opens new pathways to finding answers to interesting science questions. My interests lie in combining specific astrophysical research on star systems' formation with the educational component of student understanding. I am a well-rounded

researcher with experience in observational astrophysics, theoretical astrophysics, and physics education research. I am prepared to continue developing my research skills through interesting projects that synthesize stellar system formation with how students persist through introductory physics classes.

## Appendix C

### Letter of Recommendation

Dear Selection Committee,

I am submitting this letter in support of Jane Smith's application to the graduate program at University. Jane is a physics major and astronomy minor and I have been a faculty member in the school of Physics and Astronomy as well as the Astrophysical Sciences and Technology PhD Program since 2015. I have known Jane as a student in two of my upper level astrophysics courses that she took as a part of the minor. These courses were Stellar Astrophysics and Extragalactic Astrophysics.

Stellar Astrophysics was a course with ten students enrolled that I taught in Fall 2016, all upper level students pursuing the minor. Jane performed well in the course and obtained the third highest grade in the course. She consistently had one of the top scores on homework assignments and exams. The final project for the course was a computational model of a star. Through her class presentation and final write up, it was clear that she understood the material and succeeded at the programming aspects of the project. She provided meaningful feedback to the other students to help them when they were stuck. Overall, Jane was an interested and engaged student in the course and completed her work satisfactorily. She did not go above and beyond in the course, and I had a feeling that she was somewhat bored by the material.

The following spring, Jane took my Extragalactic Astrophysics course. This course was a bit unusual in that the upper-level undergraduate section was combined with the graduate level version of the course for a total enrolment of 25 students (about half graduate, half undergraduate). As such, I expected more work from the graduate students and for them to take a leadership role in interacting with the undergraduate students during group discussions. Jane finished with an A in the course and had the second highest undergraduate score overall. Her homework scores were the best in the class, higher than even our graduate students. She regularly completed the portions of the homework that were intended only for the graduate students. She was an active participant in class discussions and showed a clear understanding and ability to communicate through the daily assigned reading reflections and the final project. Though she performed well in both of my courses, I found her to be much more interested and excited about the material in Extragalactic.

I have also seen Jane give a number of presentations on her research. She has presented at the undergraduate research symposium and the senior capstone seminar. Jane is an above average speaker. She demonstrates a clear and thorough understanding of her research area but does not always convey a high level of enthusiasm. I suspect that this is likely due to nervousness, because while talking to her one on one about her research, it is clear to me that she is highly motivated and enthusiastic. I think with practice she will gain confidence in her presentation skills.

In summary, I believe that Jane has the experience, enthusiasm, and drive to be a successful graduate student. She has a clear mastery of the background physics material and is an excellent problem solver. She is enthusiastic about her research area and extragalactic astronomy in

general. I believe she will excel as a PhD student and I recommend her without any reservations. Please feel free to contact me if you have any questions.