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WOMEN'S PERSISTENCE INTO GRADUATE ASTRONOMY PROGRAMS: THE ROLES OF SUPPORT, INTEREST, AND CAPITAL

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This study uses data from qualitative interviews with successful female graduate students in astronomy in order to explore female student success in undergraduate physics departments. The aspects include the role of faculty support through an undergraduate's education, the provision of engaging introductory courses, the importance of community among students, and more. However, the results also suggest that there are other factors that influence the success of the students, such as a love of the field of study and available resources in terms of different types of capital. The authors argue that in order to increase the numbers of female students in the fields of astronomy and physics these considerations also need to be addressed.

KEY WORDS: *women in science, astronomy, work/life balance, support, women in physics*

1. INTRODUCTION

Women currently comprise 38, 39, and 17% of astronomy undergraduate students, graduate students, and faculty, respectively (Ivie et al., 2013; Mulvey and Nicholson, 2012; .Mulvey and Nicholson, 2014) . This is a higher representation of women than the closely related field of physics, which is often housed in the same department as astronomy. Women in physics comprise 22, 18, and 14% of the various ranks, respectively. This is shown in Fig. 1. Although this startling comparison exists, almost no literature addresses the lives and experiences of women in astronomy to understand how they got to, and persist within, the field. In contrast, the field of physics has been robustly treated in the literature. Many articles have examined the lives and experiences of women in physics. These studies range from examinations of learning differences (Kost et al., 2009; Kost-Smith et al., 2010; Lorenzo et al., 2006; Miyake et al., 2010; Pollock et al., 2007); experiences of women in undergraduate institutions (Whitten et al., 2003, 2004, 2007); and the experiences of women in graduate physics programs (Curtin et al., 1997; Dabney and Tai, 2013; Hollenshead et al., 1994).

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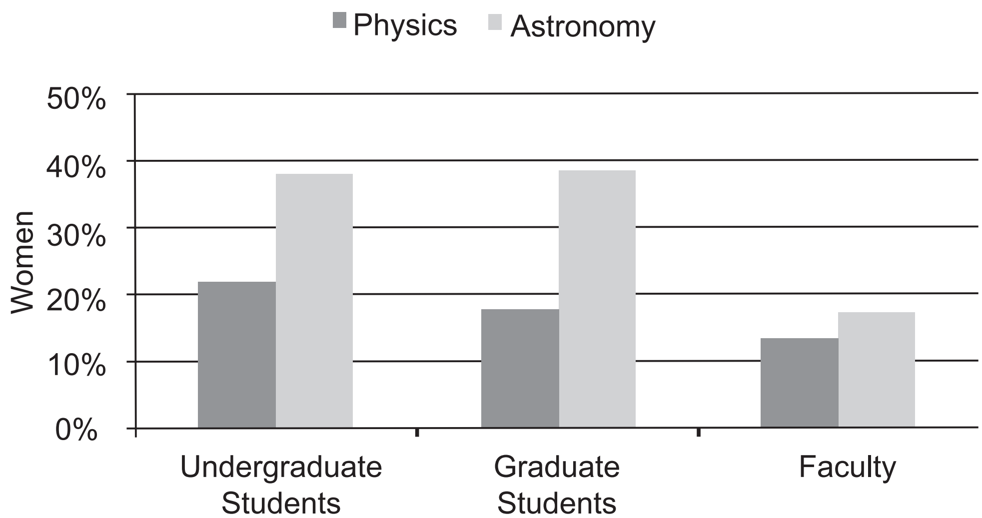

FIG. 1: Percentage of women in physics and astronomy (Ivie et al., 2013; Mulvey and Nicholson, 2012; Mulvey and Nicholson, 2014)

The research on women in physics can be used as a proxy to motivate and give methodological support to research concerning the lives of women in astronomy. Astronomy and physics are very similar in content, research, and degree pathways and are often combined in the same department. An undergraduate education in physics is often seen as a necessary step to pursue graduate work in astronomy. Even research between the two fields can become indistinguishable, such as work in nuclear astrophysics, which focuses on nuclear processes that give life to stars and the physical makeup of the universe. The similarity between the fields makes their disparity in gender diversity curious and warrants further exploration.

2. RESEARCH GOALS

In our research, we are looking to determine if successful female undergraduate students who have continued on to become successful graduate students in astronomy mention aspects that the Whitten et al. (2003) model of the loom note as important for student experiences of success in physics programs. The model of the loom offers a metaphor for understanding how departments of physics support their undergraduate women students. We were curious to determine if our respondents discussed their undergraduate careers in ways that show that the student experience components of the loom model are applicable to their undergraduate experiences, thus enhancing their persistence into graduate school. Little to no research exists on women in astronomy; therefore, research on women in physics will be used to motivate and support this work. This is a reasonable proxy due to the similarities between the two fields.

This secondary analysis will help us better understand how women persist and succeed in graduate-level astronomy. Documenting women's experiences in astronomy can be used as a comparison point for physics because of their stark similarities. It may be possible to document best practices from the field of astronomy that may be useful in the field of physics, helping to recruit and retain more women students. We have two goals this work will address:

- Research Goal I: Determine if the student-specific aspects of the Whitten et al. (2003) loom model for undergraduate women in physics are present in narratives of women in graduate astronomy programs.
- Research Goal II: Rebuild the applicable aspects of the loom model to accurately reflect the experiences of women who successfully persisted into graduate-level astronomy.

3. BACKGROUND

The work done by Whitten et al. (2003, 2004, 2007) is particularly compelling and a useful starting point when examining astronomy. The researchers in the Whitten et al. (2003, 2004, 2007) studies conducted site visits at undergraduate physics departments across the United States to interview faculty and students, observe classes, and interview some administrators. The data they collected were rich in context and offer the most recent and exhaustive qualitative study of women in physics. From this work, two models emerged that were useful for thinking about the lives of women in physics, and by extension astronomy. They were the educational pathways model (Whitten et al., 2007) and the loom model (Whitten et al., 2003).

Although the educational pathways model is important for studying women in physics education as they enter the field, the model that is applicable to our research is that of the loom (Whitten et al., 2003). Aspects of this model will be used as a unit of analysis in this paper and will first be thoroughly discussed. Whitten et al. (2003) described the factors that made departments attractive to female students using the metaphor of a loom, which supports the faculty and department, as well as the students, in a way that encourages academic success. According to Whitten et al. (2003, p. 244): "Institutional and departmental structures form the framework of the loom, supporting faculty members and students in their work" and "The faculty members form the warp of the fabric, providing continuity and structure. The students provide the weft, interacting with faculty members and one another to create a strong fabric." Successful schools, according to this model, have many components, such as a faculty support structure, family friendly policies for faculty, and supports for faculty and junior faculty. The warp of their model comes from faculty creating structure and continuity within the department culture, which should optimally be experienced as "warm and inclusive" by students (Whitten et al., 2003, p. 249).

The warp in the loom model is created through development of several key pieces within the department. Whitten et al. (2003) focused on the introductory course and recommended more innovative subjects and interactive pedagogy as a way to form subject interest in students. Such approaches to teaching physics have been shown by others to increase the success of women students (Lorenzo et al., 2006). Mentoring is another important component of the warp, and is recommended over all four years of the undergraduate program as a way of "identifying and including potential majors" and integrating them into the department culture (Whitten et al., 2003, p. 251). Another aspect of mentoring, which was identified as important in this study, was an orientation toward undergraduates and the presence of faculty who are "dedicated to teaching and to the welfare of the students" (Whitten et al., 2003, p. 251).

Spending funds on students was identified as another way to create a warm and inclusive culture, and Whitten et al. (2003) noted several methods for achieving this, such as having a student lounge, providing tutoring (preferably from older majors), providing laboratory assistants, hosting undergraduate-level seminars, starting physics clubs, and having department-wide social activities "such as picnics and softball games," (Whitten et al., 2003, p. 251) to which potential majors should be invited. A final and significant aspect of the warp is creating a female-friendly departmental culture, which includes fostering a cooperative learning environment, mentioning female and minority scientists in course work, applying physics to "environmental and other social issues" (Whitten et al., 2003, p. 253), encouraging student-faculty research, and being mindful of female student safety concerns on campus.

Many of the aspects discussed by Whitten have also emerged in other research concerning students and higher education. Of particular interest are studies focusing on inclusive cultures and mentoring that help to foster retention. One way of fostering student success is by looking at their climate experiences in their education programs. Climate is defined as the "current attitudes, behaviors, and standards of employees and students … that concern the access for, inclusion of, and level of respect for individual and group needs, abilities, and potential" (Rankin and Reason, 2008, p. 64). In studies focusing on underrepresented undergraduate students in higher education, it has been shown that climate experiences can impact learning and a student's ability to become a part of the campus community (Cabrera et al., 1999; Carini et al., 2006; Pascarella and Terenzini, 2005; Reason et al., 2006). Furthermore, the issues of chilly climates in the science, technology, engineering, and mathematics (STEM) fields has been an area of interest for years when studying women as undergraduate students all the way through faculty positions (Blickenstaff, 2005; Curtin et al., 1997; Hill et al., 2010; Seymour and Hewitt, 1997). The message of these articles is that chilly hostile climates freeze women out and need to be corrected for women's eventual success.

Beyond fostering a positive climate, it is also important to ensure that women students in physics receive the critical mentoring necessary for their success. Mentoring from departments is a necessary step because women students may not readily receive mentoring from other common university components such as student affairs and residential life, which can often have a dearth of available faculty and staff (Nagda et al., 1998; Tinto, 1993). Research has shown that student engagement with faculty can increase student success and satisfaction with their college experience (Astin, 1993; Kuh and Hu, 2001). Such interactions with students could include research, long-term independent projects, and apprenticeships (Pascarella and Terenzini, 2005; Reason et al., 2006; Sadler et al., 2010). The literature clearly demonstrates a need for faculty and research interactions called for by Whitten et al. (2003).

Given the importance of the Whitten et al. (2003) work on the loom and the success of women in physics education, we wanted to compare our interview data to aspects of the loom model to see if students included any of these aspects in their narratives. Specifically, in this paper we look at the undergraduate experiences of five women who are successfully navigating graduate astronomy programs to see which aspects of the loom are present in their success stories.

4. METHODS

Previous work by the authors focused on five women astronomy graduate students as they finished their Ph.D.'s in an astronomy department that was home to 37% women faculty (R. Barthelemy, M. McCormick, and C. Henderson, The educational pathways of five U.S. women in a woman-friendly astronomy department, in preparation). This representation of women faculty is over twice the national average of women astronomy faculty members (17%) (Ivie et al., 2013) The department was also described as having an overall positive working climate and network of support for women interested in having children. Consequently, it was characterized by the authors to be a woman-friendly department and offered an interesting case study to understand women's unique experiences when gender equality seems to exist.

In the analysis of these women graduate students, we attempted to recreate the Whitten et al. (2003) loom model for their graduate experiences and model their career goals by rebuilding the Whitten et al. (2007) educational pathways model (R. Barthelemy, M. McCormick, and C. Henderson, The educational pathways of five U.S. women in a woman-friendly astronomy department, in preparation). Our results showed that women relied on support from faculty, post-doctorates (post-docs), and other students to succeed and benefited from strong undergraduate educations. Looking at their career goals, it was found that the standard pipeline model of women moving directly toward tenure track positions at research institutions failed to accommodate their goals. These women were largely concerned about work/life balance and being able to have families as research faculty members.

In this paper we are trying to determine if the undergraduate education of these five women include the criteria mentioned in the Whitten et al. (2003) loom model. The authors conducted a secondary analysis of the interviews, looking for experiences and stories of the undergraduate educational experiences of the participants.

4.1 Data Collection and Analysis

Data were collected in the form of in-depth and in-person interviews that were conducted as part of a site visit to a U.S. research-intensive university. The interviews were conversational in form and allowed the participant to guide the discussion. Participants were prompted with open-ended questions such as "Tell me about the pathway that lead you to astronomy," which allowed them to recall what was important to them and share relevant experiences that may have not been considered by the authors. This made the women's experiences and stories the center of the data collection (Harding, 2001; Reinharz, 1992). This approach to research is known as feminist standpoint theory, which collects and analyzes data through the lens of women research participants and recognizes their experiences as unique and meaningful (Brooks, 2007; Harding, 2001). Each interview participant was given the opportunity to review her interview transcript to make any changes and ensure it was a reflection of her lived experience.

The interviews were transcribed and then coded and analyzed by the first two authors. The interviews were first coded line-by-line for actions and specific experiences. Then, the interviews were reexamined in light of these codes to look for over-arching themes that existed between participants. Continually analyzing interviews in the context of one another is called the constant comparative method (Charmaz, 2006). In this process, the researchers controlled for bias by discussing why they applied certain codes and also by creating memos about the process to reflect and document how they came to certain decisions.

4.2 Role of the Researchers

The first two authors each brought a unique view to the paper to process the data; the first author as a single mother and sociology graduate student, and the second author as a queer Hispanic male and physics education graduate student. Confronting and including our identities was important in validating the results with one another and being aware of possible bias in the coding process. For example, if the second author did not see a situation as inherently sexist from his perspective as a man, the first author would consider the data from the perspective of a woman to see how their respective privileges and experiences may have shaped their data coding. The same process was used for many other data aspects such as issues of race, parenting, working in the laboratory setting, and more.

4.3 Participants

Participants were recruited by e-mailing a student list-serv at the targeted U.S. research-intensive universities. To participate in the study, each person had to fit three requirements: (1) gender identify as a woman; (2) be pursuing a Ph.D. in astronomy or astrophysics; and (3) have passed their qualifying or equivalent exam. This paper will focus on one graduate department and the five women participants who were enrolled in this program and consented to an interview. Each of the participants attended a different undergraduate institution, ranging from a small liberal arts college to a large research-intensive university. The participant demographics are given in Table 1.

TABLE 1: Participant demographics

Participant	Year	Undergraduate institution	Undergraduate degree	Race
Annie	6	All women's college	Astronomy and physics	White
Cyndi	4	Research intensive	Physics	White
Bishi	4	Research intensive	Astrophysics and physics	Indian
Kate	3	Small public university	Physics	White
Pat	3	Small liberal arts	Business[1]	White

[1]Study participants took many undergraduate astronomy and physics classes.

The majority of the participants were White and in the later years of their graduate programs, as was delimited by the participant requirements. Four of the five participants were what may be considered "traditional" students, in that they received an undergraduate degree in astronomy or physics and then pursued a graduate degree in astronomy. However, Pat did not fit this mold. She first pursued a degree in business, worked for a few years, and then returned to college for training in physics to then apply to a graduate program in astronomy. Pat was slightly older than the traditional age of a senior graduate student, which would be late twenties. More details on their ages will not be given to protect their identities.

It should also be noted that each of the participants had an undergraduate major in physics except for one, who went back and took many physics and astronomy classes before continuing on into graduate school for astronomy. Of the participants with degrees in physics, only two had actual astronomy undergraduate degrees. This helps support our earlier claim that physics is a necessary step for astronomy. However, what was clear about all these participants was that they had significant experience and interest within the field of astronomy.

5. RESULTS

The results section will unfold in three sub-sections reflecting the major parts of the loom model suggested by Whitten et al. (2003). These sections are the loom itself, the warp, and the weft. The loom itself represents the frame, which is said to be a department and institution that supports faculty. The warp is the threads running vertically in the loom frame and represents the support faculty provided for students. Finally, the weft is the threads, which run horizontally, and represents the support and female-friendly atmosphere that students create. The following section will outline each of these three parts in detail, and culminate by suggesting how the model might change to accommodate the lives of these five women in their undergraduate programs.

It is useful to point out some limitations in the data before continuing. Unlike Whitten et al. (2003), we only have interviews with graduate students and not the faculty and administrators. This limits our ability to triangulate the results or make large generalizable claims. However, what we do have are the unique stories of five women who continued on from their undergraduate programs to successfully pursue graduate degrees at a major U.S. research university. By examining their experiences in light of the loom model, we can determine if these successful students describe their undergraduate education in ways that reference the characteristics that Whitten et al. (2003) deemed important to student success.

5.1 The Loom

The loom, or rather the frame of the loom, is the institutional and departmental support provided to faculty. This includes aspects such as having family-friendly policies to support and retain women faculty (as well as men), creating an atmosphere that facilitates teamwork between faculty members, and supporting junior faculty so they can succeed. Essentially, Whitten et al. (2003) suggested that a department needs to first tend to its faculty and make sure they are successful and happy so they can transfer this environment to their students.

Ensuring this kind of atmosphere may also help to provide students with stronger role models and show them that women can succeed in physics (Whitten et al., 2003). While the data in our project do not address this portion of the loom, because our interviews were limited to students, we noted in our results that one student specifically identified a female faculty as being a role model for her, which she found very important. Pat explained the importance of having a female faculty role model that demonstrated work/life balance between family and her career:

> *P: She teaches, she is very happy, has a family. I just saw her as the picture of success… Her outcome is often seen like kind of settling for less,…but she's still has a tenure job, is still doing research in her spare time and has, like, a pretty comfortable life.*

Pat saw her undergraduate advisor as being able to both have a career and a family, something she later explained she wanted for herself. With respect to the loom model, Pat's description of her advisor hints at some aspects constructing the frame of the loom. Her advisor was supported enough to be able to teach and do research while also having a family, which suggests the department had family-friendly policies identified by Whitten et al. (2003). Pat's advisor demonstrated balance, something Pat recognized and wanted. Her advisor gave her a new vision of success, which was having a balance between career and the rest of one's life while moving forward in one's selected field.

5.2 The Warp

In the Whitten et al. (2003) model, the warp of the loom is created by the faculty. The warp is the supportive threads within a weave, which run horizontally and serve to hold the threads of the weft together when creating fabric. According to Whitten et al. (2003), there are several components to the warp, the most significant of which is creation of "a warm and inclusive department culture," which benefits all students, but in particular is of importance to women. Because women value relationships, teaching proficiency and contact with instructors, the warp can have a huge impact on the success of women in a department, according to Whitten et al. (2003).

Whitten et al. (2003) identified several important pieces of the warp, including the introductory course; mentoring of students by faculty for the entirety of their undergraduate program; spending department funds on students through providing various resources; creating a female-friendly department climate; and administrative factors around recruiting, outreach, and engagement of alumni. The administrative pieces of this model are beyond the scope of our work because we did not consult with administration. However, we can use the data we gathered from our participants to validate other findings of the Whitten et al. (2003) research, in particular by looking at the participants' descriptions of their experiences in order to see if their narratives include some of these aspects.

5.2.1 The Introductory Course

An important feature in the loom model was the role of the introductory course in women's choice of the physics major. For Annie and Kate they discussed the introductory course as an influence in their choice of major. Cyndi and Pat reflected on their experiences as being positive:

> *A: [I took] astronomy 101 to get my science requirement out of the way … And like, within 3 weeks I wanted to do astronomy for at least my major. Yeah I just, what I found interesting about it then and still I find interesting is that, um, you only get the light from, distant objects and then you, it's sort of a puzzle you have to put together and figure out what's going on. And my teacher … my intro to astronomy wasn't great, but he managed to convey that, and I was kind of hooked. I switched majors immediately.*

> *K: I took intro physics and I decided after my first semester that I would major in physics. And my professor at the time … found out that I changed my major … to physics, and she got super super excited and was like "You need to do research with me."*

> *C: I took astronomy, like an intro to astronomy class, um, and, I ended up doing really well in it and I really liked the teacher.*

> *P: The intro physics class … it was a lot harder, I think, than I was expecting, but it was good. I mean I, I enjoyed it. I had really good teachers at [University] and I had a good um, a good group of kids that you know, were my classmates.*

For Cyndi, Pat, and Kate, the instructors themselves are important; for Annie, Kate, and Pat, the information being conveyed was important in their narratives. In these examples, we also see the beginning of some relationships with faculty and with classmates, which are components of "a warm and inclusive department culture" mentioned by Whitten et al. (2003). These examples support the Whitten et al. (2003) focus on the introductory class and show significance to these participants, who are successfully navigating graduate careers in astronomy. Although the women do not mention the teaching methods or specific aspects included in the courses, which was part of the Whitten et al. (2003) focus, it is noteworthy that all of them mentioned their introductory astronomy courses in their narratives.

5.2.2 Four-Year Mentoring

The next component identified in the Whitten et al. (2003) model of the warp is four-year mentoring. Some of the pieces Whitten et al. (2003) found in successful schools included invitations into department culture, open-door policies by faculty, and faculty members who "felt themselves to be dedicated to teaching and to the welfare of the students" (Whitten et al., 2003, p. 251). Importantly, Whitten et al. (2003, p. 251) noted that the successful schools were skillful at "identifying and including potential majors in their first year."

This is exemplified in the previous quotation by Kate, where she mentions a professor who got "super, super excited" when she found out Kate switched her major and expressed a desire to do research with the student. Pat and Bishi also discuss the importance of their relationships with teachers throughout their programs, from whom they were able to receive mentoring:

> *P: One of the astronomy professors there who was sort of like the undergrad advisor, um, she was just a really good advisor and mentor and I ended up doing research with her for a couple of quarters ... I still, like, ask her for references and ask her for advice for stuff.*

> *B: ... we actually developed like a personal relationship and to this day when I go back and work with him I'll just sit in his office and work and, like, you know, be able to just be like, "Hey," stop him in the middle of his work and be like, "help me with this,". . . . I was very lucky to be able to make that relationship happen because I think, you know, one person molded me into the scientist I am, and it's always great to have that mentor figure to go back to, you know? Any time there is a problem in grad school, I'm like, ask him [for] advice, you know, which is really nice.*

Cyndi also mentioned her research advisor at her undergraduate institution and his role in mentoring her:

> *C: He was a really nice guy but he was a bit more, um, you know, encouraged me to figure things out on my own. Like he didn't, he didn't hold my hand as much as my advisors at [university] did, and I think probably at that time I had more physics experience, I had more research experience, so he let me figure stuff out more on my own.*

Cyndi also brought up the importance of post-docs in terms of mentoring. We found that a few participants mentioned this, and this was an unexpected finding of our research:

> *C: We were able to work out our schedules so that he was always around and he was always interested in what I was doing and what progress I was making and he would always want plots to show him. Um, that was the first time that, uh, a professor [post-doc] like started inviting me to group meetings and I had to start like presenting the research I was doing to other people in, in the research group and so that was, that was a new experience because I was so used to only communicating science to one person who already knew pretty much what I was doing (chuckles).*

Annie also mentioned the importance of a post-doc's mentorship in her undergraduate success:

> *A: She was a post-doc, and she, basically is just sort of the advisor that teaches, she teaches you everything she tries to put you in the best position they can for grad school and I don't know when the idea of grad school occurred to me, but by the time I was working with her it was my career goal to go there. And so she gave me a really good project that led me to a paper which I published she was essential in getting me into grad school.*

From these examples, we see that mentoring was a pivotal part of the successful experience of undergraduate school for these women. Interestingly, our participants noted the importance of post-docs, who were more available and had more time to offer the students in terms of mentoring. Post-docs were not mentioned in the work of Whitten et al. (2003), yet they were perceived by students as important parts of the departmental culture. Another aspect of the undergraduate experience that was particularly helpful for these women concerned monetary investments made to the students by the department and faculty.

5.2.3 Spending Money on Your Students

Whitten et al. (2003) noted that spending money on students was a method for creating an appealing student culture within departments. They outlined several key ideas that were found in schools they identified to be successful, such as having a student lounge, offering a tutorial service for students, having laboratory assistants, offering undergraduate-level seminars, having physics clubs, and sponsoring social activities. According to the Whitten et al. (2003) research, these components encourage students to understand how important departmental culture is and to take responsibility for their part in creating the culture.

Only one of our participants, Bishi, mentioned a study space specifically: "We all had this one building with a reading room where we all did our homework." From this quotation, we cannot discern whether or not it was a departmentally provided space, but it does speak to the usefulness of defined spaces where students can work together. However, other than this example, our participants did not mention the other components of Whitten's category, unless we consider post-docs as laboratory assistants. If we do that, then that particular aspect of the loom model was very important.

However, for the most part our participants did not describe experiences that fit under this heading of the model proposed by Whitten et al. (2003). Instead, what we found was that the examples from our participants that address spending money on students have to do with opportunities for doing research with faculty, traveling with faculty to telescopes, and going to conferences. Kate discussed a mentor/professor who wanted to do research with her:

> *K: Right after our first semester of physics she took me to [State] to do, to Peak [Telescope], to do observing with her, and I was just like, "This is awesome!"*

Bishi discussed working on research with a research scientist at her undergraduate institution and the longer-term nature of their work together. She continued to work with this mentor throughout her undergraduate career: "I worked on our project um, for, with him for about a year and a half or so." Pat talked about an astronomy professor with whom she did research for a couple of terms, as well as mentioning opportunities for summer projects with other professors:

> *P: So that was like a summer project that I worked with him looking at the disks around young stars that would potentially eventually form planets … That was a cool project and I actually went to Hawaii to observe with him.*

Cyndi's experience was unusual in that she had multiple opportunities for undergraduate research experience, both at her undergraduate institution and at a research institute:

> *C: I did a summer um, research assistantship at the [Observatory], which is in [American City] … during my third year of college and the summer after my third year, um, I worked actually for a geophysicist at the [Oceanography Institute]. … I worked there until I managed to get a paying job actually at [University] with one of my physics professors. Um, so I did that during my fourth year. Um, I actually did my astronomy at the [University] campus.*

Cyndi's experience also included a trip to a conference: "I mean, they were able to send me to, like, to the American Astronomical Society conference, so it was, like, my first conference I had ever been to."

Annie was encouraged to perform research, and received a grant to do so. "Um, and they had a grant, um, to pay me so I just had to find someone to work with so I started working with the [Museum], um yeah, which was awesome." Annie also worked with a post-doc who gave her access to resources:

> *A: And so she gave me a really good project that led me to a paper which I published … she also, um, sent me to a big conference, well, went with me, she introduced me to people. Um, I went observing, um, at telescopes a couple of times with her.*

Cyndi also mentioned the assistance of a post-doc in her research experiences; although this does not quite fit the "lab assistant" component of the Whitten et al. (2003) model, it is noteworthy that two of our participants mentioned relationships, mentoring, and research opportunities that resulted from working with post-docs. Cyndi also mentioned the assistance of other undergraduate students in the laboratory, which is something Whitten et al. (2003) discussed in their work: "There were other undergrads in the lab and often uh, often they were a good resource."

As our evidence shows, there are many ways in which department spending on students has impacted these students positively; however, they occur mainly in the areas of opportunities to conduct and write about research, opportunities to visit telescopes, opportunities to attend conferences and be introduced to other researchers, and opportunities to receive funding to conduct research.

5.2.4 Be Sure the Department Climate is Female Friendly

In the Whitten et al. (2003, p. 253) research, they suggest that a female-friendly department is important because in "typical departments, the culture is informal but so male-dominated that women feel uncomfortable and out of place." Among their suggestions for making a department more female friendly are things like monitoring student culture for sexist remarks and behavior. They also suggested fostering a cooperative learning environment, as opposed to a competitive one, to meet the needs of female students. In addition, Whitten et al. (2003) suggested mentioning female and minority physicists in lectures, emphasizing applications of physics to environmental and social issues, and making sure female students feel safe in the department alone or in the evenings.

The final recommendation of Whitten et al. (2003) in this section addresses faculty conducting research with students as a way of encouraging more informal relationships between faculty and students. Although we found evidence of this with the participants in our study, we put this under the previous section of the Whitten et al. (2003) model because it seemed to coincide with financial supports for students in many of our participants' examples. The one example we found that did not fit the financial supports area was an opportunity Cyndi discussed in which she was invited to publish with a professor. Cyndi was invited to group meetings by a professor in her research group, and was encouraged to fully participate in the research. This experience resulted in a first-authored publication for Cyndi while she was still an undergraduate student:

> *C: Yeah so he, yeah, that was really scary because I was used to making plots and making tables and things like that, but he was like, "No, I want you to actually write it." And so I was like, "Uh, ok." So yeah, so that was my first experience writing.*

All of the other instances of working with faculty have been discussed in the spending money on your students section or the four-year mentoring section, where the student/faculty relationship aspect of these opportunities was discussed. The importance of these research opportunities is evident on many different levels, and our findings show that the students valued these experiences and built meaningful relationships with faculty.

Although our data did not show support for some of the Whitten et al. (2003) recommendations in this area—such as mentioning female and minority physicists in lectures by emphasizing applications of physics to environmental and social issues, or concerns about safety within the department—we did find that the cooperative learning environment was important for our participants. Bishi, in the discussion where she mentioned the reading room, also talked about working with her peers on homework, and forming small study groups in which students would ask each other for assistance. She described this as a "cooperative" environment:

> *B: [My] Friends in other departments, they are like [when referencing the people in my department being friendly and cooperative], "I can't imagine that being the case because it's so competitive in our field" like, say biology and things, where the classes are so big and so competitive that no one helps each other. Uh, [named university], like the physics department was actually really, like, friendly and helpful.*

Similarly, Annie identified the importance of collaborative learning with her peers. Pat also mentioned the importance of the small group of students in her cohort and the helpfulness of studying together. Our data indicated that the presence of a collaborative learning environment was helpful for these women in undergraduate physics programs because a couple of our participants noted that they would not have been able to succeed without the assistance and support of their peers.

However, our data included a couple of examples from our participants that point to more typical, male-dominated departments. Annie went to an all-women's college and found camaraderie within her undergraduate study group. Although her primary physics and astronomy classes were only populated by females, Annie's upper-division classes were mixed with males. She explained that they did not work together:

> *A: I barely talked to any of them … They intimidated me. Um, a lot of them, I think this was, I just think a lot of guys, especially at [university] project this attitude of knowing everything, being perfect … um, occasionally if we were going to ask them questions about homework, it would be kind of condescending. Um, but other times it was kind of normal, not, not really sure. (Laughs) It was just so not often that I would talk to them.*

Annie's experience set her apart from the male students in her mixed courses. Her male counterparts were perceived as projecting attitudes of superiority, in which they did not struggle in the courses. Annie did not fit in with this style of doing physics; she admitted to struggling and found success with the aid of her female colleagues. Kate encountered a similar reaction from the male students at her mixed-gender small liberal arts school. However, her story unfolded slightly differently:

> *K: They [male students] would do homework together and I would try to like, get in on it, but nobody would, like, tell me when they were, like, hooking up, and it was definitely a little awkward for a while. I didn't feel like I had uh, like, a supportive peer group of other physics majors at first. After, after the first semester I think they realized that I was smarter than all of them (laughs) … Then they liked to keep me around, (laughs) um, so then it, things went a little more smoothly.*

Kate's initial rejection from the undergraduate males was foregone when she outperformed them on examinations. To even find acceptance in physics Kate had to be better than her male counterparts and demonstrate intellectual rigor. Similar strategies of superior performance have been cited in the literature as a means for women of color to succeed in physics (Ong, 2005). Such a coping mechanism is not a practical tool for women to persist in physics. All women should have access to the field whether they are the best, mid-range, or the worst in the field.

Kate differed from Annie in that she had no female colleagues and was alone when the male students refused to work with her. She persevered by outperforming the males and became a welcome addition because of her classroom superiority. Without this display of intellect, she may not have been accepted into their groups, leaving her isolated in her studies. For the other three participants, gender did not appear to be an issue in their inclusion in group studying. However, these examples speak to the more typical experience of females in male-dominated physics departments, and show what types of performance may be required by females in those settings in order to succeed; they also serve to underscore the importance of the female-friendly department atmosphere for the success of women students in the fields of physics and astronomy.

Although Whitten et al. (2003) identified two other aspects of the warp of the loom—recruiting and outreach and the role of alumni and alumnae—these particular aspects of the warp do not apply to our participants' experiences. However, our data do confirm that much of what Whitten et al. (2003) have recommended for increasing the participation of women in undergraduate physics was indeed present for the participants in our study.

5.3 The Weft

The weft of the loom is the horizontal threads (students), which are held in place by the frame and warp of the loom (faculty) (Whitten et al., 2003). Whitten et al. (2003) explained that the faculty must create an environment that fosters student teamwork, and if this is in place the students can work to support each other and form a female-friendly environment. Specifically, Whitten et al. (2003) suggested that students can take on more formal roles in order to accomplish this, such as running the physics club, staffing laboratories, and organizing social events. Students can work as a group to form an inclusive environment that is inviting for all students.

To begin the process of building such a community, it is important that faculty role model this behavior and that the behavior is visible to students (Whitten et al., 2003). It may also be necessary to have coursework structures that allow student group work, e.g., no curved exams. The participants in our study discussed aspects of the weft, such as relying on other students to help them get through their course work and even conduct research through group study and collaboration with peers.

All five participants described studying in groups in their undergraduate coursework. These groups not only facilitated their own learning, but also were described as the mode in which they persevered in their undergraduate classes. For Cyndi, her study group gave her "sanity" and grew out of social interactions that extended outside the classroom:

> *C: I think it was really because of the other physics majors that I was able to keep my sanity and stay with it, um, because they were, they were great and they were some of my best friends in college.*

Bishi experienced a collaborative studying environment that was facilitated by a space the students carved out for themselves in a building. They used this space to gather and work together on their assignments. She also explained that her department's cooperation was unique within her university, which was discussed previously in the warp section.

Pat's study group was created within a diverse atmosphere that accepted her. The acceptance she received was not related to her being an outsider due to gender, but due to her age when she entered the program. She was returning to school after working in an unrelated field, but she was not the oldest student in her study group:

P: I think the oldest one of us was like 40 something … a pretty diverse group and um, it was really good, we all got along well, we'd all study together …

For Annie and Kate, their entrance into study groups came from explicitly gendered experiences. Annie, at first, "banded together" with the other female astronomy majors. She explained that without them she would have not survived her first class:

A: If I hadn't had that [female study group] I would have, I would have failed my first class at [University] I'm pretty sure …

These stories show the importance of building meaningful relationships with other undergraduate students to facilitate a collaborative community of learning. This was exemplified by the evolution of Cyndi's study group from social outings and in Pat's group, which came from an atmosphere that disregarded age in student interactions.

Collaboration with peers for Cyndi went beyond the classroom and coursework. When Cyndi was hired into a research group with a professor who was very busy, she found support from her fellow undergraduates in the laboratory: "There were other undergrads in the lab and often, uh, often they were a good resource." This was also true for Annie. In one of her research experiences, all the undergraduates were put in a room together to figure out their research. Collaborative support among students helped aid their success in research.

It is evident that our participants experienced a collaborative learning environment, which was helpful in navigating their undergraduate careers successfully. Although Annie and Kate did not initially have female-friendly experiences, they were able to form relationships that enabled them to experience collaborative learning and be supported by their peers; all of our participants noted the importance of these types of learning experiences.

5.4 Other Contributors to Success

Although the data we collected showed significant support for some of the aspects of the Whitten et al. (2003) loom in explaining the success of the participants in their graduate careers in astronomy, those aspects did not explain all of the success these women experienced. In the stories of these women, there were other factors at work in building their success that did not come from the departmental climate of the institution, but that were nevertheless very influential in aiding their success as graduate students. The first of these factors is a love for the field of astronomy, which stands out in the language used by the participants when discussing their pursuit of astronomy, and the second factor is the number of opportunities they had while in their undergraduate (and in one case, high school) careers. These factors may have implications for departments that wish to recruit and retain women students.

5.4.1 Love of Astronomy

When examining the data for themes, the language used about the field of astronomy stood out. The women who were in these undergraduate programs loved the field of astronomy, and their language reflected that emotional connection. Each of the women has a narrative to describe how she came to the field, and in many of the stories, we see that the puzzling nature of the concepts of astronomy or its ability to pique their interest draws the women to the work:

> *K: … right after our first semester of physics she took me to Arizona to do, to Peak telescopes to do observing with her and I was just like "This is awesome!" Fell in love, did some reading, and the rest is kind of history. … I found it interesting like a puzzle so, I just had a knack for math, but as far as in the physical world, it was just curiosity about the things around me … I was doing astronomy and I loved it.*

> *C: My dad … was like "Are you bored, in school?" And I was like, oh, finally someone gets it, and so he took me to the book store and bought me Cosmos by Carl Sagan. And, and he gave it to me and he was like, "When you're bored in school read this," … so he got me that astronomy book and I was pretty much sold, um, after that.*

Bishi spoke about her father, and how he influenced her interest in the field:

> *B: And so back when he was studying … I guess it's a true passion in life, and like, uh, physics and astronomy and things like that, … as a child he just kind of talked to me about it. I used to pay attention and find it interesting and in particular I remember actually him telling me about time dilation, and I was probably like 7 or 8, I was really young, um, and it was just the concept obviously. He wasn't telling me any math really, but he just said, you know, "Time slows down" and that was just really weird to me because it just didn't make sense. How does time slow down, you know? You never question seconds on a clock, and so, time slowing down is just mind boggling to me.*

Pat spoke of a lifetime attraction to the field of astronomy, in spite of her decision to pursue a different degree in her undergraduate career:

> *P: I really liked astronomy just ever since I was little, just, I don't know, it fascinated me just learning about the universe, seeing the pretty pictures of the galaxies and everything.*

Annie spoke about her original interest in opera, and how a course in astronomy changed her career trajectory:

> *A: Ok um, when I went to college, I actually wanted to be a opera singer … I tried to get into this music theory class that I wasn't qualified for, left this schedule hole and my advisor, who in the music department suggested astronomy because it's supposed to be easy. … And like, within 3 weeks I wanted to, do astronomy for at least my major. … What I found interesting about it then and still I find interesting is that, um, you only get the light from, distant objects and then you, it's sort of a puzzle you have to put together and figure out what's going on. … I was kind of hooked. I switched majors immediately.*

What is interesting about these stories from the women is that they all have passion about the work, or note that the field intrigues them and makes them want to continue to study the topic. This passion motivates their success in their undergraduate programs of study, and may help them persist in the field. Recent research by Hazari et al. (2012) has found a relationship between motivation for pursuing physical sciences and career productivity. Those who pursued physical science because they enjoyed thinking about it were found to be more productive in their careers, as measured by grant funding and author publications, than those who were motivated by other reasons, such as money and past performance. However, another item of note when considering the success of these women concerns available resources.

5.4.2 Opportunities and Access to Resources

The other notable aspect in the participant data concerns the sheer numbers of opportunities these women had in terms of their undergraduate and in two cases, high school, careers. These women had access to resources that aided them in their undergraduate studies. For example, in Cyndi's story, her parents recognized early on that she was not being challenged in school and offered her an opportunity to discover something different through reading popular scientific literature. When she later needed more challenges, they knew to direct her to community college while she was still in high school. The direction to community college gave Cyndi a huge advantage compared to others because she was offered opportunities while in high school to teach with her professor. Similarly, Bishi was able to convince her parents to enroll her in an undergraduate course at a nearby university while she was still in high school. Parents without higher education may not have made these same recommendations to their children, partly because they may not have been aware that these options were available to high school students.

Not only was Cyndi able to attend community college courses while in high school, she was also able to call upon a family friend who helped her choose an undergraduate school. This same family friend offered her further academic assistance in terms of a paid position over summer break while she was an undergraduate. In reading Cyndi's story, one sees Cyndi's ability to meet with others in the field and ask for the assistance she would like to receive, such as employment or research opportunities. One also sees a succession of mentors stepping in to help her advance herself in the field throughout her high school and undergraduate education. Although some of these opportunities are due to her abilities in the field, the sheer number of opportunities available to Cyndi shows that she is an outlier, having experiences that would not be available to most students pursuing the same field of study. Not all undergraduates or high school students interested in the field of astronomy would have been able to seek out the people in positions to aid them and then successfully advocate for themselves to get the opportunities that Cyndi was able to get, in part because these abilities speak to a set of skills and a level of confidence that not all young women may have.

Parental support was available to some of these young women in the form of encouraging their thought processes and encouraging them to pursue fields of interest to them. If we look at Bishi's story, we see how her father encouraged her in the study of astronomy and physics. Her father, she explained, had wanted to study in the field, but chose to pursue an engineering degree instead as a way to support his family. Bishi described her father's interest in astronomy and physics as a "true passion," and noted that his discussion of this passion with her was an influence over her own choice of the field. However, this story points to another consideration, that of economic security. With Bishi's father, we see that he chose another field of study for economic reasons. A similar experience of not choosing astronomy due to economic considerations was seen in another participant's story.

Pat chose a different path for her undergraduate career, due to financial considerations. She shared that she wanted to be sure to be able to make a living and that she decided that business was the preferable route for her first degree. It was not until later in life, when she had become somewhat disenchanted with her work, that she decided to take the risk of pursuing astronomy for a career. This speaks to an unspoken but apparent premise that astronomy is a passion, but is not a valid career choice for everyone, in part due to economic concerns. Although Pat has been successful in her current pursuit of her graduate-level astronomy degree, her pathway is very different from that of the younger women, admittedly due to financial reasons. It was only when she had earned money and gained some economic freedom that she believed she could pursue astronomy as a legitimate career. None of the other participants mentioned financial concerns when discussing their educational pursuits, which is significant. Actually, some of their stories speak more to the fact that economic concerns were not present.

When discussing the pursuit of their educational goals, many of the women mentioned research opportunities and funding opportunities, but these were opportunities that were open to them. None of the women spoke of not having the necessary resources to do the things that were required of them to further their educational pathways. In fact, when discussing applications to graduate schools, more than one mentioned the number of schools to which they applied (11 in one case; 8–10 in another), in different areas of the country, as a way of making sure they had a certain level of opportunity and choice in the pursuit of their graduate degree and the geographical areas in which they would end up living. This was significant to the authors, who, as graduate students themselves, noted that many students would not have had the funds required to submit so many applications to graduate schools. This speaks to a level of financial security that is not available to all who decide to pursue graduate education, as we saw with Pat and with Bishi's father.

There were other stories in our data that pointed to a level of economic privilege, which is not universally available to women who wish to pursue the field of astronomy. One of our participants attended a private, female-only undergraduate institution, which gave her access to other Ivy League schools and their faculty, giving her a chance to meet and work with a very high-profile astronomer. Another participant spoke of taking a year to travel abroad to pursue a career in culinary arts. She did this to be sure she really wanted to study astronomy because she was interested in both fields. Clearly, these types of experiences speak to opportunities that are not available to those with limited financial resources.

The recurring theme identified through these stories is the access to resources these young women had, either through their parents' educational levels and knowledge of higher education, the existence of family friends with connections in the field, or the financial resources available to the participants. These resources gave them advantages that may not be available to others without similar access to such resources.

One way in which to understand these opportunities and access to resources concerns capital. In his work on different types of capital that are available to people in society, Bourdieu (1984) spoke of economic capital, cultural capital, and educational capital. Bourdieu (1984) saw these forms of capital as ways to differentiate between different social classes in society because those who are the most privileged in our society have access to the greatest volume of all three types of capital. Together, he saw these three types of capital as a "set of actually usable resources and powers" (Bourdieu, 1984, p. 114). Economic capital, of course, refers to funds, cultural capital refers to tastes and distinctions developed as a result having access to funds and to the other members of one's social circles, and educational capital refers to one's educational attainment.

A further consideration of class and opportunities that class affords people is Bourdieu's notion of "habitus." According to Bourdieu (1984), one's habitus is the environment in which one grows up and is exposed to the world. In one's habitus, one is framed to behave in a particular manner; these skills and outlooks on life are not considered to be learnable by those who have not grown up in similar situations because they would require a lifetime of learning. This is particularly evident in terms of social class, according to Bourdieu (1984). One of the things learned in one's habitus is how one speaks to others and draws upon social capital, or the relationships one has with other members of one's social class, in order to improve one's position in life (Bourdieu, 1984). This is evident in the story of Cyndi, who uses her family's social ties to guide her choices in terms of her education and to further her position by requesting opportunities for work and/

or funding. Cyndi was also able to create the relationships and ask the questions that helped her gain more opportunities than perhaps would be available to others without such social capital or internalized expectations of advancement that come from a habitus of social class and privilege.

The role of social class and the privilege it offers needs to be considered here. Although discussions of class are not the norm, class plays a role in the stories of these women (Mantsios, 2003). One approach to class comes from Mantsios (2003, p. 41), who describes it simply: "difference in class determines where they live, who their friends are, how well they are educated, what they do for a living, and what they come to expect from life." It is clear that several of our participants came from a background in which financial constraints were not considerations in their decisions to study astronomy. The one student who did identify this as a barrier was able to pursue astronomy as a second career, after attaining a buyout from a position in an unrelated field, which allowed her the financial freedom to do so. In other words, she had to obtain capital to be in a position to enter the field of astronomy. It is possible that there is something about the physical sciences themselves, particularly physics and astronomy, that precludes students with less capital—be it social, cultural, or financial—from entering the field. If these students do enter the field, they may be at a disadvantage if they are unable to advocate for themselves or ask for the opportunities that would benefit them in terms of creating pathways into graduate education.

There are many scholars already looking at the issues of social class in higher education (Evans, 2009; Martin, 2012; Reay, 2003; Reay et al., 2001) who note a pattern of access to educational opportunities, which is based in social class and continues in spite of programs that encourage people from lower social classes to engage in higher education. There are others (Lareau and Weininger, 2003; Scherger and Savage, 2010) who look particularly at cultural influences in this process. Importantly, Lareau and Weininger (2003, p. 597) noted that in order to understand cultural influences, we need to examine "micro-interactional processes whereby individuals' strategic use of knowledge, skills, and competence come into contact with institutionalized standards of evaluation," or as we described previously, ways in which students are able to mobilize particular skill sets and knowledge in order to ask for what they want and need in an educational setting, which helps them advocate for themselves. Scherger and Savage (2010) also noted the importance of having parents who encourage and support the activities of children, such as we saw with some of the participants in our study, as a method of attaining cultural capital that aids students in terms of higher education.

In the works by Reay (2003) and Reay et al. (2001), the authors addressed issues of habitus. Some young women in their studies who were entering or choosing higher education sometimes altered their paths due to feeling as though they did not belong with the people they had met and interacted with in university settings. These women also had a more "instrumental" approach to their education, in that they were doing it to advance themselves and their families financially, versus pursuing education as a means in and of itself. Finally, the women in their studies admitted to some geographical constraints in terms of their study, which is not something we encountered with the participants in our work.

Additionally, Martin (2012) noted the importance of a level of financial security, which allows students the freedom to pursue more available options as part of their undergraduate work. These opportunities may not be available to students who have to concurrently work to support themselves in school or who have care responsibilities at home that compete with their schooling (Martin, 2012). Clearly, what emerges from this discussion is a complex picture of the numerous types of support that contribute to students' educational achievement, and resources in terms of different types of available capital can make a difference in a student's educational success.

6. DISCUSSION

6.1 Research Goal I

From our discussion of the different aspects of the warp and the weft outlined by Whitten et al. (2003), it is clear that some of the aspects identified in their study as helping students succeed were present and acknowledged by the participants in our study, even though the questions asked of them did not address that research. The women in this study reported experiences of aspects of the Whitten et al. (2003) warp that helped to sustain and support their student careers and these experiences of support and mentoring were identified by them as critical to their continuation and success in their programs of study. The data suggest that these positive influences may have enhanced their ability to eventually succeed in a prestigious research-intensive university's graduate program. It is also clear that the aspects of the weft identified by Whitten et al. (2003) were meaningful for these graduate-ready astronomy students in terms of the creation of a female-friendly culture with a collaborative learning focus.

This female-friendly culture was echoed beyond just the loom model and has been suggested throughout the STEM education literature (Blickenstaff, 2005; Hill et al., 2010; McCullough, 2002). One interesting case study of gender diversity in physics was conducted at Grinnell College, where over half of their declared physics majors are women (Schneider, 2001). This was achieved by having reformed interactive introductory classes, contacting all women who express interest in the physics major, providing social opportunities for women and all students in physics, and offering first year research experiences to students. Their efforts are strongly in line with the model of the loom and many of the undergraduate experiences afforded to the women in this study. Anecdotally, at least, it is possible to suggest that adopting such methods in mainstream physics culture may support women's overall success.

6.2 Research Goal II

We offer a slightly revised version of the loom presented by Whitten et al. (2003). In our model, the warp is created by both faculty and post-docs, who have been shown to be influential in the academic careers of these young women in astronomy graduate programs. However, the support that creates the framework for the loom needs to be altered to include additional pieces in order to reflect what we found in our work.

In previous research (R. Barthelemy, M. McCormick, and C. Henderson, The educational pathways of five U.S. women in a woman-friendly astronomy department, in preparation), the authors proposed a model of the loom that included the importance of a positive undergraduate experience for graduate students in astronomy. In the model we present now, we would add the additional pieces we found to be integral to the success of the women in our study. First, we would add the importance of a passion for the field. Second, we would add that a foundation of available resources greatly enhances the chances for the success of women in astronomy and physics. As explored previously, available resources were invaluable to the success of these women. The resource that was most important was capital (Bourdieu, 1984; Lareau and Weininger, 2003). This was evident in terms of having access to funding that allowed for pursuit of the field of astronomy (financial capital); personal relationships with others in the general field of science or education, which offer connections to opportunities to further one's study (social capital); and having knowledge about how to navigate the academic environment and make the most out of potential opportunities, such as being able to take physical science courses at community colleges or universities while in high school (cultural capital).

The two parts we have added to the loom are represented by the base of the loom. This base holds up the loom framework, and makes it possible for the other aspects to interact and support these women in their undergraduate institutions. The updated model is shown in Fig. 2. Much of the loom has been preserved because our data supported the importance of certain aspects of the model for our participants. However, the additional aspects gleaned from the data have been included as a base for the loom because these pieces played an important role in contributing to the success of these women in their graduate astronomy education. We also added post-docs to our model, given the importance of their role to the participants in our study.

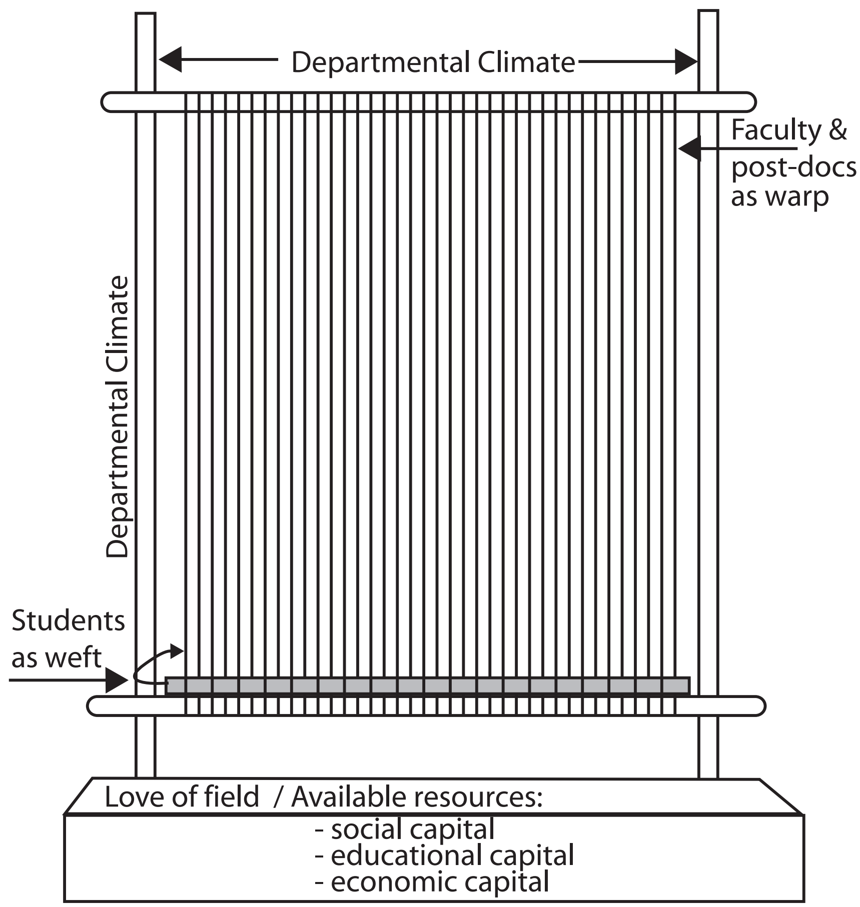

FIG. 2: The loom rebuilt (Whitten et al., 2003)

6.3 Implications for Astronomy and Physics Programs

This research has shown that the availability of resources has a significant impact on the success of women in undergraduate astronomy and physics. Given this, it may be helpful for departments to consider ways in which they can assist female students to attain success in these fields. Our findings suggest that the provision of financial resources, such that students do not have to work outside of their programs of study, can greatly aid in their success. Offering students funding and research opportunities allowed the female participants in our study to persist in the field and obtain access to important educational experiences, such as conference attendance, networking, and research with faculty.

In addition to resources, these women also loved the field of astronomy. One thing departments could do to encourage the love of the field is to continue to focus on introductory courses and the development of more engaging teaching methods to reach and hook students early in their undergraduate careers. As recent research has shown, the love of the field itself leads to better outcomes in student careers (Hazari et al., 2012), and focusing on introductory courses was recommended by Whitten et al. (2003) and was shown to be pivotal in the narratives of our study respondents.

Additionally, the role of faculty and post-doctoral mentoring made an important difference in the success of the women in this study. Departments could consider student engagement as a part of post-doctoral positions as a way to help students have greater access to mentoring and research opportunities within the field because the post-docs seemed to be more available to students than were faculty. Additionally, having more recently navigated the system themselves, the post-docs had valuable insights to share with the students. Furthermore, the post-docs were perceived as having a greater investment in the students in some ways because they were also interested in learning the skills of mentoring as part of their own professional development, according to the stories shared by our participants.

Departments may also consider offering trainings and seminars to undergraduate students, helping them understand how to navigate the world of academia, and offering them greater guidance in terms of how to ask for research opportunities and how to build relationships with faculty. These changes could easily be incorporated into the "spending money on students" aspect of the Whitten et al. (2003) model, and could help students without these types of skills develop what they would need to achieve success.

Finally, our research suggests that departmental awareness of these issues can help even the playing field for those women who do not come into their undergraduate programs with great resources. Providing those with fewer resources the opportunities and funding that these successful women were able to access, as well as offering training geared to aid understanding and navigation of the academic world, may be effective methods in helping promising women students persist in their chosen fields of study.

7. CONCLUSIONS

This analysis was undertaken as a way to determine if the student-specific aspects of the Whitten et al. (2003) model of the loom for undergraduate women in physics apply to the undergraduate experiences of women in graduate astronomy programs. We have used research on women in physics as a proxy for women in astronomy in this work because there is little research on women in astronomy, and the undergraduate backgrounds of women in physics are comparable to those of women who continue on to pursue astronomy. The women in this current study shared experiences that support certain aspects of the model of the loom proposed by Whitten et al. (2003), which have been previously outlined. Additionally, there were two other pieces of significance that came out of the data. (1) The women who were successful in their astronomy graduate programs all shared a love of the field of astronomy, which undergirded their academic successes. (2) These women also had significant levels of capital upon which to draw, in the form of financial capital, social capital, and cultural capital, which enabled them to pursue their educational endeavors. As such, we added these two significant factors to the loom model in order to show the types of support that aid academic success.

Additionally, given the importance of post-docs in the mentoring narratives of these successful undergraduate students, more research should be done on the role of post-docs in departments in terms of both mentoring and their contributions to departmental culture. The availability of post-docs and their levels of engagement with students proved important to the women in this study, and this may be an area of interest to departments of physics and astronomy, or other fields hoping to increase the level of women's participation in their programs.

Surprisingly, our data pointed to the importance of markers of social class in the stories of these successful female astronomy graduate students. This is an interesting finding of our research, and speaks to the need of further study in this area to include issues of social class and available resources as considerations when exploring success of female students in the fields of physics and astronomy, especially if educational institutions are trying to increase the inclusion of females in the field(s). More attention may need to be paid to financial support that enables students to actually participate in all of the available opportunities versus having to juggle focuses beyond undergraduate education, such as working to support themselves and/or their families.

The results of our paper clearly indicate that, with slight modifications, the student-focused aspects of the Whitten et al. (2003) loom model did apply to the stories of the participants in this study. It may be possible, with further work, to show its applicability beyond the participants presented here. Such investigations of women in astronomy may aid in the development of best practices applicable to other sciences with even lower gender diversity.

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