

Examining reasons undergraduate women join physics

Maxwell Franklin

Drexel University, Philadelphia, Pennsylvania 19104, USA

Eric Brewe

Drexel University, Philadelphia, Pennsylvania 19104, USA

Annette R. Ponnock

Yale University, New Haven, Connecticut 06520, USA

Renee Michelle Goertzen

American Physical Society, College Park, Maryland 20740

This study examines survey data from 2,129 undergraduate women at the 2015 and 2019 American Physical Society Conference for Undergraduate Women in Physics (CUWiP) in order to classify what led them to study physics. We use expectancy-value and self-efficacy theory to create a coding framework based on different types of value and efficacy expectations in order to group responses. We find that the most common attractions are social persuasion, which is due to pressure or persuasion from people around the students, and intrinsic value, which is related to the inherent value of engaging in physics.

I. INTRODUCTION

The gender disparity in physics is an urgent problem, and there is a vast amount of research studying why women either persist in or leave the discipline. Women are driven out of physics by a hostile climate and negative stereotypes, resulting in the proportion of women in the field declining at each stage [1, 2]. This is a serious issue, as greater diversity in physics results in greater diversity of ideas and a more welcoming culture for everyone hoping to learn. In our research, we look at what motivates women to study physics. We do this by leveraging both expectancy-value theory and self-efficacy. Expectancy-value theory explains motivation and states that people perform a task based on its perceived difficulty. Self efficacy, on the other hand, refers to students' belief in their ability to succeed in a given task.

Self efficacy has been used to study entrance to physics, but thus far, expectancy-value theory has only been used to explain persistence. We extend this prior work by using expectancy-value theory to explain what initially draws women to physics. We implemented these theories through careful analysis of survey responses given at the Conference for Undergraduate Women in Physics (CUWiP). This research provides insight into reasons women join physics that could be used to attract more women to the field.

II. THEORY

Our model of motivation integrates two different motivational frameworks: expectancy-value theory and self-efficacy theory. Expectancy-value theory states that an individual's motivation for performing a certain task is caused by an expectancy of success in the task and the value they give said task [3]. These expectancies are formed through previous experience in related tasks, among other factors [4]. The current understanding of this model is both psychological and developmental [5]. The psychological factor asserts that a student's expectancies and individual values are rooted in their subjective beliefs. The developmental component states that these beliefs are shaped over time by the environment and experiences of the student.

When proposing this model, Eccles et al. defined three different types of value [3]. The first is attainment value, which means that a given task supports an aspect of the student's identity. The second is intrinsic value, which means that a student finds the act of performing the task to be inherently valuable or receives enjoyment simply from doing the task. The third is utility value, meaning that the task is useful for a student's future goals. The survey responses collected showed each of these values and how they applied to a student's physics experience.

Additionally, there is a fourth component to the expectancy-value model: cost, defined as anything that keeps a student from pursuing the task [3]. In the original

model, there were three varieties of cost: the amount of effort required to succeed, the loss of engagement in other activities, and negative feelings resulting from struggle or failure [3]. These were refined and built upon through further research [6] until four main categories coalesced. These are task-effort cost, or the effort required to perform the task; outside effort cost, or the effort needed for other tasks; loss of valued alternatives, or what is forsaken as a result of the task; and the emotional cost that is required for the task [7].

As expectancy-value theory includes how well a student thinks they will perform at a given task, it is closely tied with self-efficacy. Self-efficacy is a measure of a person's belief in their abilities for a given task [8]. This is mediated by efficacy expectations, which affect both initial motivation and motivation to persevere in a task [8]. In his initial paper, Bandura defined four main sources of efficacy expectations. The first is mastery experience, which is based on personal experiences of success. The second is vicarious experience, which is based on witnessing the success of others. The third is social persuasion, which is pressure and persuasion from others. The final source is physiological or emotional arousal, the feeling one gets when performing a task. These four sources create an overall expectation of success in a student that correlates highly with engagement in a subject. Previous work has found that women are most likely to persist in STEM fields because of vicarious experiences and social persuasion [9].

Expectancy-value theory merges a student's expectation for their success with the value they assign to a task. These are fully covered through Bandura's sources for efficacy expectation and Eccles' description of the varied values and costs. In this paper we use both theories in order to study why women choose to either join or leave the field of physics. This study builds off of previous research using expectancy-value theory to study gender differences in both academic and non-academic settings [10] and why women are less likely to persist in STEM fields [11–13]. We narrow this idea specifically to women in physics using a large survey dataset of women in undergraduate physics.

III. METHODOLOGY

The survey responses used in this research were taken from a question given to attendees of the Conferences for Undergraduate Women in Physics (CUWiP) in 2015 and 2019. Most of the respondents were physics majors, but all had been involved in physics courses or research. Surveys were collected online by APS with conference registration materials, but they were not required. The question read “Briefly describe events/experiences that led you to becoming a physics or physics-related major starting from the first time you considered physics as an option to the present (please include details of the factors that influenced you initially and along the way).” We

Group	Category	Description	Example
Expectancy-Value Theory	Attainment Value	Students pursue physics to further their identity as a scientist or as a physicist	“I’ve been the ‘math and science girl’”
	Cost	Students are discouraged from pursuing physics	“I often question whether I’m in the right major because it’s so hard”
	Intrinsic Value	Students study physics for the value of physics or of science	“I was amazed by the explanatory and predictive power of physics”
	Utility Value	Students pursue physics to achieve a goal. This could be a career, success in another field, or to inspire others	“Since all engineering fields require a good physics background, I decided to pursue a physics degree”
Self-Efficacy	Mastery Experience	Students had an experience where they excelled at physics or a related field	“I realized that in my high school physics course I was doing better than other students”
	Physiological/Emotional Arousal	Students feel good while doing physics	“In high school, Honors Physics, when it was the only class I sat in and felt happy”
	Social Persuasion	Students study physics because of pressure or support from others, often teachers, peers, or relatives	“The math and physics community at my university has always been a great source of support”
	Vicarious Experience	Students saw someone they relate to excel at physics. This could be a fellow student, a relative, or any other role model	“My best friend in high school’s older sister was a physics major at Wellesley College and I thought, if she can do it I can do it too!”

TABLE I: Description of our Coding Framework

coded the two years of data in different ways. In the 2015 dataset ($n = 803$), each response had been divided into smaller excerpts [14], where each excerpt highlighted one or two motivational factors. After coding the excerpts, we recombined them into full responses. Due to time constraints, the 2019 survey ($n=1326$) was coded at the level of a full response instead of being split into smaller snippets.

In early coding of these responses, our collaborators used socio-cognitive career theory (SCCT) to focus on the educational, social, and familial factors that motivate students. They identified the categories of ‘educational experiences’, ‘people’, ‘physics qualities’, and ‘physics subjects’ [14]. Our efforts to understand the same data from an expectancy-value and self-efficacy framework led us to recode the data. We first created new categories more in line with psychological motivation theories and created matches between the old SCCT categories and our new categories. Our overarching two groups became ‘Self Efficacy’ and “Expectancy-Value Theorem”. We then performed a round of hand-coding to explore how our framework allowed for unique insights into the dataset. Two authors coded the data individually before cross-validating their results.

The first group of codes we had was ‘Expectancy Value Theorem’, which contained four categories. The first was ‘attainment value’, which was for responses that discussed a student’s identity as a physicist or a scientist. The second was ‘utility value’, which was for responses about future goals as a physicist. This was a broad cate-

gory, as it covered both career goals and less concrete objectives, such as making physics a more welcoming place for women. The third subcategory was ‘intrinsic value’, which was for responses that spoke of the inherent value of doing physics. This was divided into ‘general intrinsic value’ and categories for each specific field of physics. For example, there were many responses in which students explicitly spoke of the value of doing astrophysics. The final subcategory was ‘cost’, which contained excerpts about what students gave up to do physics or what obstacles they encountered in studying physics.

The ‘cost’ category is a good indicator of possible reasons women do not join or leave physics, and we split it into the subcategories defined by Eccles et al. and Flake [3, 7]. Though they are not represented in our tables for reasons of space, all four types of cost are present in our data. The first is emotional cost, which describes the emotional or psychological toll that physics takes. This could be as simple as a lack of enjoyment in a physics class, but we often saw it tied to gender inequities in a physics department that create a hostile environment for women. The second cost is task-effort cost, which deals with the challenging nature of undergraduate physics. The third type of cost, the loss of valued alternatives, includes responses where students had to give up something, which is often a career or a family member’s approval, in order to study physics. The fourth and rarest type of cost in our data is an outside effort cost, which describes external factors that take time away from doing physics such as family or health.

Year	2015	2019	Total
Social Persuasion	55.61%	45.39%	49.22%
Intrinsic-General	51.37%	43.09%	46.21%
Physiological/Emotional Arousal	34.54%	25.36%	28.82%
Intrinsic-Astronomy	23.31%	16.83%	19.28%
Utility Value	21.45%	10.79%	14.81%
Mastery Experience	17.33%	9.89%	12.69%
Vicarious Experience	13.84%	8.83%	10.72%
Cost-Emotional	9.89%	5.43%	7.15%
Cost-Task Effort	7.34%	2.87%	4.56%
Intrinsic-Other	7.11%	1.74%	3.76%
Cost-Other	3.18%	1.28%	1.97%
Attainment Value	0.62%	0.53%	0.56%

TABLE II: Percentage of students who expressed each code. Self-efficacy codes are in blue, while expectancy-value codes are in green.

The ‘Self Efficacy’ group contained four categories, ‘mastery experience’, ‘vicarious experience’, ‘social persuasion’, and ‘emotional and physiological arousal’, which match the four sources of efficacy expectations [8]. Codes in the first category, ‘mastery experience’, discussed previous experiences in which the student had done well in a physics or STEM setting. Codes in ‘vicarious experience’ contained experiences where a student saw others like them, such as a peer or relative, excel at physics. Codes in ‘social persuasion’ discussed pressure or support from others, such as a teacher, relative, or friend, to join physics. Finally, ‘emotional and physical arousal’ contained excerpts about how students felt when they did physics.

After coding was completed, we combined both datasets and tabulated how many responses fit into each category or subcategory of motivation. Many of the responses contained more than one category, so the sum of the categories is much greater than the overall responses. The overall data provide us a clear picture of what inspires women to pursue physics as an undergraduate study.

IV. RESULTS

Of the over 2000 responses, the most common motivational factors by far were social persuasion, which was noted by 49.2% of the students, and the intrinsic value of physics in general, which was said by 46.2% of the students. There were also many students who mentioned the physiological or emotional arousal of doing physics and the intrinsic value of astronomy specifically. Beyond that, no other single trait was very common as no others were found in more than 15% of respondents. This is partially in line with previous research [9], as we found social persuasion to be prevalent but did not find vicarious experience to be very common. Exact percentages for each code, both in each year and overall, can be found in Table II. Of note is the discrepancy in code counts between 2015 and 2019 despite average response length only

slightly higher in 2015. This could be due to a differing level of detail in the responses or it could be an artifact of the different coding methods used on each dataset. This will be examined in future codings of the data, in which we will standardize our process.

Another result of the data is the rarity of cost. The most prevalent cost code was emotional cost, which most often manifested in impostor syndrome or discouragement from others. However, this appeared in only slightly over 7% of the codes. As some students reported more than one form of cost, the total percentage of codes in which students mentioned a cost to doing physics was only 11.9%. While we did not expect to find many responses involving cost due to the nature of our question, it would have been conceivable that women in physics faced so many costs that including them would be unavoidable. Despite it not being part of our question, the expectancy-value framework is valuable for studying the costs faced by women in physics [12], and it is something we will examine in future re-definings of our categories.

Our coding framework had two main sections: codes regarding the value students found in physics and codes regarding a student’s self-efficacy towards performing physics. We did not find a clear discrepancy between the two overarching categories, as both had codes that were common and codes that were rare. From this, we conclude that there is not a bias in the stage of expectancy-value theory that influences women to join physics. As many women join based on their expectation of success as from the perceived value of the work.

V. CONCLUSIONS AND FUTURE RESEARCH

We found the most common reasons for women to join physics were social persuasion and the intrinsic value of physics. This finding has strong implications for how to attract more women to the discipline. Social persuasion can be implemented by having teachers give support to girls and women studying physics, as has been done in the STEP UP program. It is important for teachers and

mentors to be intentional in recruiting women to physics and for institutions to create policies that support the development of student community. Cultivating intrinsic value is more difficult, but it is possible since students mentioned specific ways in which their intrinsic value emerged. To attract more women to physics through this, teachers should be explicit about how physics ties into other subjects and set up opportunities for students to perform physics at a young age, such as in science fairs or demonstrations at local schools.

Additionally, we were able to validate our coding scheme, as the proposed mix of self-efficacy and expectancy-value theory described the vast majority of the survey responses. Though these frameworks are not often combined, they work together well to describe motivation since self-efficacy theory covers the ‘expectation of success’ factor in expectancy-value theory. One quirk of the data that contradicts our coding scheme is the disparity in response types between the 2015 and 2019 datasets. This is most likely due to the differing methods of coding and will be examined through more rounds of iterative coding, in which we will update our coding scheme. One change that could be made is that the ‘intrinsic value’ code is currently extremely broad, which contributes to its prevalence among responses. We will examine this code more closely and refine it if necessary. We also plan to compare how our expectancy-value coding scheme reveals different insights than the earlier SCCT codings.

In the immediate future, we plan to shift focus from motivation to retention and map whether or not the different categories of motivation that women show correlate with their retention in physics. To this end, we have a follow up survey that was administered to the 2015 respondents. Down the line, other questions asked on the initial survey could also be studied through this framework to create a more holistic picture of qualities shared by women who remain in physics through their undergraduate education. Using natural language processing, we will create a predictive tool for retention based upon survey responses.

Another theory which could be leveraged to explain retention is the theory of interest development, which is divided into a four phase model: triggered situational interest, maintained situational interest, emerging individual interest, and well-developed individual interest [15].

This coding framework would not be applicable to our current dataset because respondents are overwhelmingly in the later stages of this model. However, if our question pertaining to motivation is given to students at earlier stages in their physics career, perhaps in a post-class survey, then it could be possible to discern a relationship between motivational factors that pull women towards physics and the speed at which they move through the stages of interest development. This could also be done at even earlier stages in a physics career, such as high school.

Though we do not yet have the data with which to do this, our motivational framework could be applied to reasons that women leave physics as well as why they enter the field. As all the survey respondents are women who are invested enough in physics to attend a conference, we would need a much larger dataset in order to get a sizable number of women who have left physics. This work would be a more thorough exploration of our cost category, taking place when those costs have grown enough to overwhelm the value women receive. In this way, expectancy-value theory is well suited to studies of this nature and it would allow researchers to view retention through a lens that is not often used in the physics education research community. Similar studies have been done for the wider STEM community [13], though no quantitative studies exist specifically for physics.

Expectancy-value theory is a powerful tool for studying motivation, but thus far it has only been used in the physics community to determine persistence. By using it to classify initial motivation in physics, we add a new framework with which to determine ways to attract women to the discipline.

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