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Katarina Pantic & Jody Clarke-Midura

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# Social interactions and practices that positively influenced women's retention in their computer science major

Katarina Pantic <sup>a</sup> and Jody Clarke-Midura<sup>b</sup>

<sup>a</sup>Teacher Education Department, Weber State University, Ogden, Weber, USA; <sup>b</sup>Instructional Technology and Learning Sciences, Utah State University, Logan, Utah, USA

## ABSTRACT

**Background and Context:** Despite over 30 years of research on broadening participation, women are still underrepresented in Computer Science (CS) education. While enrolment in CS majors has increased, women earn only 18% of the CS baccalaureate degrees in the US.

**Objective:** Most research focuses on why women leave CS. This study explores factors (i.e. social interactions and practices) that support retention from the perspective of women who persisted in their CS major.

**Methods:** We interviewed ten participants first by separating them in two focus groups and then by using individual in-depth interviews.

**Findings:** We identified four types of social interactions that support retention of women. In terms of practices, we present four of the most frequent practices, and four practices that characterised retention of women at the periphery. These findings add nuanced understanding of factors that support retention of women through the theoretical lens of legitimate peripheral participation in communities of practice.

**Implications:** This study has several implications for CS departments on how they can support women's retention, such as by supporting internships, propagating work-life balance and training faculty and students on the importance of legitimacy and support.

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Periphery; legitimacy; retention; women; computer science (CS)

## Introduction

For decades, the number of women in Computer Science (CS) education has been lower than in any other STEM field (Ashcraft et al., 2012). Women earn only about 18% of the CS baccalaureate degrees (National Science Foundation, 2019) despite the fact that they earn approximately 57% of the baccalaureate degrees overall (National Science Foundation, 2018) and the fact that CS field itself experienced a 74% overall increase in enrolment from 2009 to 2015 (Computing Research Association, 2016; National Academies of Sciences, Engineering, Medicine, 2017). Low retention of women in CS majors is the most prominent during the first two years of being in a program (Biggers et al., 2008; Miliszewska et al., 2006; Stephenson et al., 2018), when as much as 26.6% of already low

**CONTACT** Katarina Pantic  [katarinapantic@weber.edu](mailto:katarinapantic@weber.edu)  Teacher Education Department, Weber State University, McKay Education Building, Room 335 1351 Edvalson St, Ogden, Weber, 1304, USA

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numbers of Freshmen and 22.2% of Sophomore women drop out of their CS majors (Stephenson et al., 2018).

Such low numbers are problematic for a variety of reasons. Gender misbalance is unethical (Wilson, 2002), as it creates a socially inequitable field (Miliszewska et al., 2006; Trauth, 2011). It is unfair, as it translates into lost opportunities for women (Cuny & Aspray, 2002) whose lack of computing skills puts them at an immediate disadvantage (Crow, 2014; Vee, 2013). It deprives the field itself of necessary diversity, one that helps the field remain competitive (Ashcraft et al., 2012; Wilson, 2002) by having diverse consumers represented in the production process (Trauth, 2011). Finally, gender misbalance creates societal losses: when women are absent, the society loses on creativity, knowledge, discourse (Barton et al., 2008; Cuny & Aspray, 2002), valuable perspectives (Ashcraft et al., 2012) and innovations that women could generate (DuBow, 2013; Schnabel, 2013). Not to mention that gender diversity was proven to have positive effects on collaboration and productivity of software development teams (Catolino et al., 2019; Vasilescu et al., 2015).

In the past 30 years, scholarship has investigated retention of women in CS by focusing on gender differences, contextual factors inside the major and or external factors, such as family or work-related factors (see, Pantic & Clarke-Midura, 2019). However, only a small number of studies use some type of a theoretical lens (Cphoon & Aspray, 2006; Pantic & Clarke-Midura, 2019; Singh et al., 2007), a need for which has been repeatedly pointed out in literature (e.g. Nelson and Veltri, 2011; Singh et al., 2007; Trauth, 2011). According to Collins and Stockton (2018), for example, a balanced use of a theoretical framework, one where there are direct links between the framework and the research design, can enhance the quality of studies that use the qualitative approach.

In this paper, we use Legitimate Peripheral Participation (LPP) in Communities of Practice (CoP)(Lave, 1996, 2009; Lave & Wenger, 1991; Smith, 2009; Wenger, 1998b, 1998a, p. 2000, 2009; Wenger et al., 2002; Wenger-Trayner & Wenger-Trayner, 2015) as a framework to both design the study and interpret the results. From this theoretical perspective, retention can be construed as ongoing and increasing social participation inside a CoP (Lave, 2009; Lave & Wenger, 1991) of one's CS major. Such participation depends on practices and social interactions we engage in, which is why to understand women's retention in CS majors, we need to understand which practices and social interactions enable their ongoing participation inside their major (Guldbert and Mackness, 2009). To that end, we pose the following theory-driven research question:

RQ1: Which social interactions and practices influenced women's ongoing participation (i.e. retention) in their CS majors?

## **Review of literature**

### ***Theoretical framework***

As we stated above, this study focuses on understanding which social engagements and practices within a CS major provide a context for ongoing participation (i.e. retention) of women in a CS major. To that end, we use the lens of Legitimate Peripheral Participation (LPP) within Communities of Practice (CoP) (Lave, 1996, 2009; Lave & Wenger, 1991,

p. 2011; Smith, 2009; Wenger, 1998b, 1998a, 2000, 2009; Wenger et al., 2002; Wenger-Trayner & Wenger-Trayner, 2015) to examine retention of women in a CS major.

LPP within CoPs views learning as an increase in social participation in a CoP (Wenger, 2009). As such, learning is interdependent with the practices and social interactions CoP members are engaged in (Lave, 2009; Lave & Wenger, 1991). LPP within CoPs, therefore, provides a useful platform to discuss retention of women in CS majors, because retention can be construed as increasing social participation inside a CoP of their major (Pantic, 2020). Thompson (2005) calls the process of increased participation inside CoPs a “virtuous circle” (p. 152), one which allows members of the community to remain motivated in a given CoP through active participation. According to Thompson (2005), the more engaged we are in a CoP, the more we learn and identify with that practice, which in turn keeps us motivated to remain engaged in that same practice (aka persist or be retained).

### ***Communities of practice***

CoP is a construct that describes a particular model of learning (Hoadley, 2012), where a group of people, such as professors and students in a CS major, with mutual concerns, problems or passions about a topic “deepen their knowledge and expertise in [an] area [of mutual interest] by interacting on an ongoing basis” (Wenger et al., 2002, p. 4). This process implies working together, sharing information and helping each other (Cassidy & Gurm, 2016). To participate in a CoP of her major, a woman needs opportunities to observe and interact with seasoned members who are involved in meaningful practices, and an opportunity to play with different routines and roles of the field (Rogoff, 2003). Retention inside a CoP depends on members’ passion, commitment (Wenger, 2000) and a sense of connectedness (Hemmasi & Csanda, 2009). If, however, practice is intangible, competences rigid, or there is lack of identification with the community, members will not persist (Probst & Borzillo, 2008).

Interestingly, CoPs can have a complex structure and consist of different fractal or mosaic layers of embedded subcommunities (Lemke, 1997). Inside a CS major, for example, fractal structure is reflected in the existence of different clubs, tutoring centers and other more informal CoPs, such as an informal community of gamers. In addition, this theory posits that knowledgeability does not exclusively develop inside one CoP. According to Lemke (1997), to develop true mastery of practice, it is often necessary to participate (aka have multimembership) across different CoPs. A typical example would be the link between school and work for any college student.

### ***Legitimate peripheral participation (LPP)***

Active engagement in a CoP, however, is not the only pre-requisite for learning (Wenger, 1998b). Engagement also needs to be meaningful, which means that newcomers need to have both an active role in their learning (Rogoff, 1995) and access to the right learning opportunities (Wenger, 1998b). The process of enculturation of newcomers in a CoP is defined as LPP (Lave & Wenger, 1991), while members’ persistence depends on whether they identify or dis-identify with the community in question (Wenger, 2010).

LPP, however, is by no means a linear acquisition of skills. Instead, learning happens within two modified forms of participation, *peripherality* and *legitimacy* (Wenger, 1998b). Peripherality is an empowering act of learning in an environment that is designed for

newcomers, where the pressure and risk are lessened, while special explanations and supervision are provided in a form of “apprenticeship” (Lave & Wenger, 1991) and access to a full range of professional activities is granted (Lave & Wenger, 1991). Otherwise, if new members are kept from participation, the whole experience can be disempowering (Lave & Wenger, 1991).

Legitimacy, on the other hand, is the act of acknowledging newcomers as competent members, regardless of the fact that they are still learning (Wenger, 1998b). When acknowledged and valued, learners can develop a sense of belonging to the community and a desire to keep engaging. Legitimacy also refers to the authenticity of practice newcomers are exposed to (Lave & Wenger, 1991), or the level of alignment between what they are learning and the practices that are actually useful in the CoP of their choosing (Guzdial & Tew, 2006).

### ***Factors influencing computer science retention of women in the U.S***

After conducting a systematic literature review (Pantic & Clarke-Midura, 2019), we found that existing research investigated the topic of retention of women in CS from three different angles: gender differences (individual factors), institutional factors, and external factors. The following section provides a brief overview of existing literature.

#### ***Individual factors***

From early research on retention of women in CS majors, we learned that women enrolled in CS majors reported having less computer experience (Denner et al., 2014; Gürer & Camp, 2002; Margolis & Fisher, 2003; Margolis et al., 2000), less programming experience (Liu & Blanc, 1996; Ragsdale, 2013; Staehr et al., 2000), less computer usage (Clegg & Trayhurn, 2000), lower sense of belonging (Blaney & Stout, 2017) and or less background knowledge on computers and programming (Liu & Blanc, 1996; Roberts et al., 2012) when compared to their male cohorts. Consequently, women often reported feeling overwhelmed and intimidated by programming and terminology in their introductory CS classes (Liu & Blanc, 1996; Roberts et al., 2012). Lack of prior experience was found to be a hindrance to retention (Buzzetto-More et al., 2010), a predictor of attrition (Katz et al., 2006), and it was found to negatively affect women’s confidence (Margolis & Fisher, 2003). However, women’s prior experience was found not to be connected to their success in introductory CS classes (Katz et al., 2006), while possession of high technical skills was found to increase their satisfaction with their major (T. L. Lewis et al., 2008) and was positively associated with their persistence (Milesi et al., 2017). Research has not identified any gender gaps between the success of men and women in more advanced CS classes (Vilner & Zur, 2006).

Additionally, some studies found that women felt uncomfortable (Liu & Blanc, 1996; Staehr et al., 2000; Wilson, 2002) by the predominantly geeky culture of CS men who seemingly “dream[t] in code” (Margolis & Fisher, 2003). Such and similar stereotypical perceptions (e.g. Cheryan et al., 2011; Cheryan et al., 2013; Fisher et al., 1997; C. M. Lewis et al., 2016; Wang et al., 2017) have long contributed to the underrepresentation of women in CS (Cheryan et al., 2015). For instance, Staehr et al. (2000) found that women were unwilling to ask “dumb” questions, and or compete for resources at hand in their first CS classes, if they perceived them to be stereotypical.

Women's retention was also found to be influenced by their self-efficacy beliefs (Ashcraft et al., 2012; Fisher et al., 1997; Rubio et al., 2015; Singh et al., 2007; Wilson, 2002). In comparison to men in their cohort, women reported having lower programming abilities (Ashcraft et al., 2012; Beyer, 2014; Fisher et al., 1997; Rosson et al., 2011; Singh et al., 2007; Wilson, 2002), lower self-efficacy (Beyer, 2014; Frieze & Quesenberry, 2015; Rosson et al., 2011; Wilson, 2002) and lower sense of belonging (Blaney & Barrett, 2022). They also perceived themselves to be slower learners (Margolis et al., 2000), and were more likely to rate themselves low on math ability, intellectual self-confidence and competitiveness (Lehman et al., 2016).

While studies that focus on individual or gender differences are insightful in some ways, they are also often simplistic and deficiency-oriented (Cohoon & Aspray, 2006; Vitores & Gil-Juárez, 2016), which further perpetuates stereotypes and marginalizes women (Frieze & Quesenberry, 2015). In this study, we wish to move away from such an approach, and move more towards an approach that allows us to hear individual voices of different women (Trauth, 2011; Wasburn & Miller, 2006).

### ***Institutional factors***

As a response to criticism of studies focusing on the gender gap which were found to perpetuate stereotypes (Cohoon & Aspray, 2006; Fisher et al., 1997; Frieze & Quesenberry, 2015), another line of inquiry on retention of women in CS examined institutional structures that influenced retention. From these studies, we learned that women's retention was influenced by interior or institutional factors as well as faculty and peer interactions, classroom experience and institutional culture.

When it comes to faculty interactions, encouraging and engaged faculty were found to be one of the most influential factors on retention of women in CS (Cohoon, 2006). When compared to men, women were found to be much more likely to seek faculty help (Varma & Hahn, 2007), but were also more likely to report having negative experiences (Barker et al., 2009; Denner et al., 2014). Some other issues influencing retention were lack of role models who are women, high faculty turnover, and low teaching quality (Cohoon, 2001, 2002a, 2002b; Metcalf et al., 2018).

Women's retention was also found to be negatively influenced when women were exposed to harassment by faculty and/or teaching assistants (Bunderson & Christensen, 1995), when men dominated class communication, if class climate was too competitive (Gokhale & Stier, 2004), class material was gender biased (Benbow & Vivyan, 2016; Gokhale & Stier, 2004; Kapoor & Gardner-McCune, 2018; Medel & Pournaghshband, 2017; Miliszewska et al., 2006) and/or if faculty created a work climate in which prior knowledge was equated with being smart (Singh et al., 2007).

Several studies also found that institutional culture was often hard for women to relate to as it was perceived as overly masculine (Biggers et al., 2008; Main & Schimpf, 2017), or they felt that they needed to be intelligent, unathletic, geeky and socially detached if they wanted to integrate into the field (Bunderson & Christensen, 1995; Margolis & Fisher, 2003; Redmond et al., 2013). According to Margolis et al. (2000), such and similar stereotypical perceptions of CS (e.g. Cheryan et al., 2011; Cheryan et al., 2013; Fisher et al., 1997; C. M. Lewis et al., 2016; Wang et al., 2017), which started as early as first semester, had the power to directly erode women's interest in CS.

Finally, research focusing on the influence of peer interactions found that women were often exposed to open doubt about their innate ability to succeed in CS (Bunderson & Christensen, 1995), various types of sexist behaviour (Barker et al., 2009; Clegg & Trayhurn, 2000), preening (Benbow & Vivyan, 2016) and/or marginalization (Gokhale & Stier, 2004), all of which negatively influenced retention. Not only did they feel that they needed to prove themselves (Gokhale & Stier, 2004), but an accumulation of negative comments, teasing, belittling, and sexism made women feel undervalued and unwelcome in their CS major (Cohoon, 2001; Gürer & Camp, 2002; Margolis et al., 2000). On a more positive note, several studies suggested that interactions with peer role models who were women had a positive effect on retention (Biggers et al., 2008; Cohoon, 2002a, 2006; Cuny & Aspray, 2002; Frieze et al., 2012).

### **External factors**

Finally, literature has examined external factors, such as family, external peers, work, and cultural norms and values. From these studies, we learned that lack of external support was found to decrease persistence (Denner et al., 2014; DuBow et al., 2017; Miliszewska et al., 2006; Roberts et al., 2012; Rosson et al., 2011), while parental computing degree (e.g. Blaney & Barrett, 2022), family support (Blaney, 2021; Sax et al., 2018) and certain cultural norms and values, such as the social desirability of a CS degree for a woman, positively influenced some women's persistence (Eidelman & Hazzan, 2005; Fokum et al., 2016; Galpin, 2002; Ojokoh et al., 2014; Schinzel, 1999; Varma, 2010; Varma & Kapur, 2015). Blaney and Barrett (2022) also found that the strongest predictor of women's sense of belonging in a CS course, which is a precursor of retention according to Lave and Wenger (1991), was their *incoming* sense of belonging, which in turn is influenced by external factors. Finally, work-related experiences, such as work-life balance or internship experiences, were also found to have an effect on retention of women in CS majors (Beyer, 2014; Beyer et al., 2005; Kapoor & Gardner-McCune, 2018).

## **Methods**

### **Setting**

The sample for this study was drawn from a CS undergraduate program from a mid-size university in the Intermountain West. According to the university website, in 2018 54% of university students were women. In April of 2019, the CS department had 17 faculty members and seven temporary instructors. Of these, three were women. In a personal communication from May 2017, department administration reported having 11 women (out of 106 students) in their Junior, and 23 women (out of 206 students) in their Senior year, which was 11% of their student population in those two years.

### **Sample**

To make sure we interviewed a representative sample, we used purposeful sampling (Patton, 2002). In other words, all the participants in this study were either Junior or Senior undergraduate students in a CS major, as attrition was found to be the worst in the first two years of being in the program (Biggers et al., 2008; Miliszewska et al., 2006;

**Table 1.** Participant Characteristics.

Participant pseudonym	Age (Mean = 21.8)	Academic standing	FTS	Racial and ethnicity	Marital status	EPT
Jane	22	Senior	x	Caucasian	Single	x
Haley	25	Junior	x	Caucasian	Single	x
Adele <sup>^</sup>	19	Junior	x	Caucasian	Single	x
Joana	22	Senior	x	Latinx Caucasian	Single	x
Shelby	21	Junior	x	Caucasian	Married	x
Savannah	22	Junior	x	Caucasian	Single	x
Beatrice	22	Senior	x	Caucasian	Single	x
Maggie	22	Senior	x	Caucasian	Single	x
Monica	23	Junior	x	Caucasian	Married	x
Erin	19	Junior	x	Caucasian	Single	

Note. FTS = Full-Time Student; EPT = Employed Part-Time.

Stephenson et al., 2018). Participant characteristics are listed in Table 1. Nine of the women participated in both focus group and the interview. One woman only participated in the interview (see, Table 1).

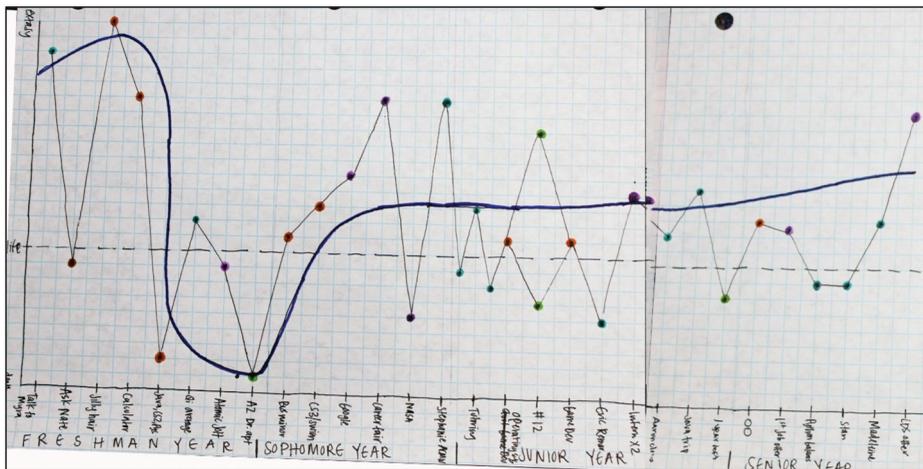
<sup>^</sup> Participant did not participate in focus groups.

### **Data sources and data collection procedures**

In this study, we applied qualitative phenomenological research design (Wojnar & Swanson, 2007), as our goal was to understand the essence of the phenomenon through women's lived experiences and their own understanding of the same. To answer the research question, we collected data from ten women with different backgrounds. The women were full-time students in advanced stages of their degree completion with different backgrounds in terms of age, academic status, marriage status, work status, place of origin (see, Table 1) and points of entry into the major. Racially and ethnically, though predominantly white, our sample was reflective of the racial and ethnic make-up of the area. For the purposes of triangulation (Glesne, 2016; Maxwell, 2012), we used data from three sources: focus groups, narratives based on journey maps, and in-depth interviews. In addition, we collected a survey at the beginning of the study to collect some demographic data on the participants.

In Phase 1, we conducted two focus groups in January of 2018. We chose focus groups because CoPs consist of different people who learn through ongoing interactions with each other and other members (Wenger, 2002). By conducting focus groups, which in their nature are interactive, we were able to investigate how our participants felt and thought about their experience (Krueger & Casey, 2014) in the program as a group. At the beginning of each focus group, participants were presented with an informed consent. Five of the women participated in Focus group 1 and four in Focus group 2. Focus groups were 60 minutes long.

During the focus groups, all the participants were asked open-ended questions about their experience in the CS major. These questions were theory-driven, designed from the perspective of the LPP in CoPs (e.g. "What do you need to do to become a recognized member of the community in your major?", "Who makes your CS major community?", "What resources particularly helped you grow?"). Both focus group sessions were audio recorded and transcribed for further analysis. Each participant was compensated with a \$10 Amazon gift card for their participation in the focus group.



**Figure 1.** Jane's Journey Map.

In Phase 2, which was conducted two weeks later, we did individual interviews with all ten participants. All the interviews were conducted in English and were on average 60 minutes long. They were audio recorded and later transcribed for further analysis. The one participant who did not participate in the focus groups was presented with the demographic survey at the beginning of their interview. Each interviewee was compensated with a \$25 Amazon gift card upon the completion of the whole interview.

The interviews had two parts: an independent narrative based on journey maps and an in-depth interview based on open-ended questions. Prior to the interview, we instructed the women to draw an illustrated map of their journey (aka journey map; Nyquist et al., 1999) through the CS program. At the beginning of the interview, the participants were first asked to share their journey map and narrate their story of persistence (Meyer & Marx, 2014) by using the map (see, Figure 1 for an example of a map they presented). The choice of journey maps was theory-driven as journey maps allowed us to look at different trajectories of participation (aka personal histories) in the context of active participation (Li et al., 2009; Wenger, 2009).

After presenting their independent narrative, the participants were asked a series of theory-driven questions about their experience (e.g. "Which experience was especially meaningful for your development throughout the major?" "Have you ever been put in a marginal position where you did not have access to all the resources and learning opportunities?" "Have you ever had an opportunity to observe or learn from more seasoned members of your major?"). We chose to use in-depth interviews in addition to journey maps because they provided us with theory-driven access to how the participants constructed and understood their own experience of retention (Jackson et al., 2007).

### **Data analysis**

To analyse the data, we used a grounded theory approach (Patton, 2002), because LPP in CoP framework does not offer a set of practices and interactions that support ongoing participation. Data analysis of the focus group and interview data (for both the journey

**Table 2.** Break-Down of Social Interactions by Gender.

Social interaction type	Interactions with women: faculty or students		Interactions with men: faculty or students		Interactions with faculty of mixed or unspecified gender	
	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%
Peer support	n = 12	12.37	n = 17	14.43	n = 68	70.20
Faculty support	n = 6	17.65	n = 11	32.35	n = 17	50.00
The role of clubs	n = 8	38.00	n = 1	4.76	n = 12	57.14
Tutor support	n = 2	14.30	n = 1	7.14	n = 11	78.57

map-based narrative and the in-depth interviews) was conducted cyclically in three stages of interpretation (Merriam, 1998). First, one of the researchers pre-coded the data by circling, highlighting, bolding, and underlying the most striking and illustrative quotes and examples (Saldaña, 2015). Next, the same researcher used professional software, called MaxQDA (see: <https://www.maxqda.com/>), to conduct a combination of open and In Vivo coding to analyze the data (Emerson et al., 1995; Patton, 2002; Saldaña, 2015). The unit of analysis in this phase was driven by the LPP in CoP theory, and it included all meaningful interactions and practices that contributed to women's ongoing participation in their CS major. This phase resulted in a total of 503 codes.

Finally, we employed axial coding, where we focused on organizing codes into related categories and subcategories (Patton, 2002) which best answered our research question. During this coding cycle, we conducted several iterative cycles of review and revision to achieve the utmost saturation of the findings. As a result, the 503 codes were organized into 13 categories aiming to answer the research question posed in this study. These categories were divided into two theory-driven groupings: Social Interactions (four categories) and Practices (nine categories). Table 2 shows the frequencies with which social interactions appeared in the data broken down by gender.

Table 3 shows the frequencies with which each practice appeared in the data. For the purposes of this study, we will extensively discuss those themes that showed up in more than ten per cent of the codes, and only briefly mention those that showed up in less than. To see the codebooks for all the categories included in this study, please see, Tables 4 and 5. These tables contain the name of each theme, their definitions and examples.

To calculate inter-coders' reliability, which is recommended as it attests to the robustness of the coding process (O'Conner & Joffe, 2020), an additional researcher was trained in the coding procedure and logic using Tables 3–4 and some additional examples from

**Table 3.** Frequencies of Codes for Practices that Enabled Participants' Retention.

Practice type	Frequency	
	<i>n</i>	%
Getting legitimacy	n = 76	22.6%
Establishing balance	n = 57	16.9%
"Lone wolf"	n = 42	12.5%
Finding a job	n = 39	11.6%
Proving you belong	n = 25	7.4%
Abandoning perfectionism	n = 23	6.8%
Finding online resources	n = 19	5.6%
"Just a really good class"	n = 18	5.3%
Other	n = 38	11.3%

**Table 4.** Codebook for Social Interactions Influencing Retention.

Theme	Definition	Example
Peer support	Examples of peers (other CS students) helping with persistence; *These exclude tutors and or women they met in ACM-W	Savannah: <i>"I need to have at least one or two friends in the class [...] if I have someone to go and sit next to and feel comfortable asking questions, like they are not gonna be like 'oh, this is just like another dumb girl who is just trying to like, you know . . . figure out the CS thing even though she has no clue and everyone is gonna hire her because she is a girl!' Like, I don't wanna feel like that. I wanna have a comfortable friend who like I can ask something 'Oh, what was that thing?' like a weird stack again and then he can explain it to me, or she can or whatever . . . and you know, it's just . . . I feel like I have a friend in the class".</i>
Faculty support	Examples of faculty members influencing their persistence	Haley: <i>"[The professor] is always great at you know, being like, not only a support in school but you know, an emotional support, . . . you know, everything, she is always making sure that I'm ok, so that's helpful, a big thing for me. It's really helped me get through the major".</i>
The role of clubs	Examples of the importance of different CS and university clubs and organizations for their persistence	Shelby: <i>"when I was a freshmen year, I was in a . . . actually, you were in there with me (talking to another woman), the Women in CS club and that was actually big support for me".</i>
Tutor support	Examples of the help and encouragement of tutors in CS Tutor Lab influencing persistence	Jane: <i>"As a freshman or sophomore, I went to the tutor lab a lot and so that's all just juniors and seniors helping you. That was huge for me. I wouldn't have made it through without the tutor lab".</i>

the data. After receiving training, the intercoder was presented with approximately 20% of randomly chosen codes for each of the two categories (Social Interactions and Practices), which they then coded deductively (Patton, 2002). Cohen's kappa ( $\kappa$ ; Cohen, 1960) was calculated to be: 0.87 (for Practices), indicating a "strong" level of agreement and 0.95 (for Social Interactions), indicating an "almost perfect" level of agreement (McHugh, 2012).

## Results

### Factors influencing retention

In this study, we focus on examining different factors (aka different types of social interactions and practices) from the perspective of LPP in CoPs that supported retention of women inside a CS major. In this section, we present our results from this study.

#### Social interactions

Four types of social interactions emerged as important for women's ongoing participation in CS: Peer Support, Faculty Support, The Role of Clubs, and Tutor Support (see, Table 2 for frequencies broken down by gender).

**Peer Support.** The most prominent type of social support for all the participants was Peer Support, which was important both emotionally and academically throughout their whole college experience.

One of the main reasons women held peer support in high regard was the educational support they received that helped them "get through" their classes. We found examples of

**Table 5.** Codebook for Practices Influencing Retention.

Theme	Definition	Example
Gaining legitimacy	Examples of getting acknowledged, such as at work, in school, in themselves etc.	Shelby: <i>"I feel like [colleague name] helps me a lot, because he's super supportive. And he like believes that I can do things. Yeah, for example, he just asked me to do – write unit tests. I was kind of like, I have no idea what unit tests are. He kind of told me, 'Well, just get started and we'll see how it goes'. I don't know. That was kind of helpful to me, because it made me just jump in and try it. It actually wasn't (...) Just his faith in me helps me believe in myself"</i> .
Establishing balance	Examples of conscious efforts to maintain work-life balance (e.g. CS- unrelated minor, exercise, etc.)	Adele: <i>"I try to balance kind of ... [..]. A physical balance or be physically active. And an academic balance, so do well on homework and a spiritual balance, so kind of focus on my church, as well. And I find that, if I kinda have the balance with my body as well as my mind, then I can succeed in what I wanna succeed in, so computer science"</i> .
"Lone wolf"	Examples of women identifying themselves as independent learners or learners who enjoyed solving problems on their own	Maggie: <i>"I had friends, but I did most of the work ... unless it's a group work, by myself. But I never. It wasn't that I wasn't like challenged, but I felt like I had that kind of a background that I felt comfortable solving the problem myself that ... I don't know, most of my assignments, like I ... I don't know. I didn't work with people as much as some other [students]. I just kind of went home and worked on my assignments (...) I think it is partially just my personality of ... Like I love people but ... I ... work with myself best"</i> .
Finding a job	Examples of how work positions contributed to their competence building and retention in the major, by helping them imagine themselves in the industry and or developing self-efficacy	Jane: <i>"Being in jobs helps a lot, like over the summer I had a pretty good internship at like a really big company and so ... they had a lot of like opportunities for like personal growth. A lot of organizations in the company that supported you with different things you wanted to learn so ..."</i>
Proving you belong	Examples of strategies they used to prove to themselves and their peers that they belonged in the major, such as open confrontation and/or working harder	Jane: <i>"I never let anything go, I always attack that. Dead on. I am just like "Hey, that's inappropriate and I am smarter than you are, so that's why I got the interview!" [laughs] "That's not ... like I don't like it when people say that 'cause that's like ... all of your hard work is like marginalized to just your gender like ... The thing you didn't even choose"</i> .
Abandoning perfectionism	Examples of changing a mindset from trying to be the best in the whole class to "giving their best" (e.g. being ok with asking for help, dropping a course and or not knowing everything)	Maggie: <i>"I think we also compare ourselves to the best in the class and sometimes we are the best and sometimes if we compare ourselves to the guys who've been doing this forever, it's hard to ... I mean, we are obviously at a disadvantage there, but if we kinda forget about that ... for me especially, if I forget about that I am like 'ok, I just need to do the best I can!' that's how I have been able to persist"</i> .

(Continued)

**Table 5.** (Continued).

Theme	Definition	Example
Finding online resources	Examples of developing and relying on Internet research skills to locate, evaluate, and use needed information effectively	Maggie: <i>"Learn how to Google the right questions"</i> . Beatrice: <i>"Yeah, learn how to Google is a big one because a lot of times people would Google really badly"</i> . (. . .) Maggie: <i>"like when they get certain errors like throwing in specific names for the errors and that sort of thing where like . . . that's something you wrote exactly and so it's not gonna match word for word with someone else 'cause if it's like your variable and something like that . . . so you gotta extract what's from . . . what's your error part and what's like the global error part, so then you Google the global one"</i> . Everyone: <i>"Yeah!"</i>
"Just a really good class"	Examples of classes that kept them interested in the program and/or provided a valuable learning experience (authentic practice)	Joana: <i>"Then it was like . . . I wrote down some classes that was like a small reason why . . . Then some classes a like . . . I am having a little bit more fun in this class and I wrote 'falling a little bit more in love with this one class' and it was like small little details into this like midlevel classes"</i> .

women forming study groups to go through class material, getting resources from peers, and studying other students' code, or getting feedback, advice and "*hints*" on their own code. Working next to more seasoned peers was also valuable, as these women were both learning the trade and what it meant to be an expert from their peers. In her interview, Savannah described her study group as essential for her retention, as she reached out to them on regular basis for resources, or questions about dysfunctional code and or computing concepts.

Another reason was the sense of belonging that the women developed within their peer communities, as a result of being accepted and respected. In that respect, Savannah reported feeling well-integrated and accepted:

I'm usually able to get along with the members of my team, like my ideas are heard and I hear their ideas, so I feel like—just all those little dynamics with my peers make me feel really included, and make me feel like happy to go and see them and joke around with them and make things with them.

As a result of such feelings of acceptance, Savannah enjoyed going to class and working on projects inside the major which was a big factor influencing her retention. Other women reported having similar feelings in relation to how the friends they had inside the program helped with their sense of belonging.

Finally, peers were found to influence women's retention by providing emotional support. We found numerous examples of women reporting the importance of having someone to "*sit with*", joke with, or talk to, or having someone who encouraged them, validated their emotions and calmed them down when needed.

**Faculty Support.** Faculty support was another consistent influence on the retention of all the women in this study. This type of support came from faculty, both men and

women, with support from women faculty being mentioned in 17.65% of the cases (see, Table 2 for details).

Overall, faculty support included both technical and emotional type of support, as it can be seen from the following example:

She is always making sure that I'm ok, so that's helpful, a big thing for me. It's really helped me get through the major. (...) Not only do we work in research and she, you know, guides me through that ... but every time I'm in her office, you know, talking about "here's the code," she is always like "ok. I appreciate that the code is going well! How is [sic] other parts of your life going? How is school?" and then we talk.

In other words, what was important for Haley's persistence was having a professor who took special interest in her life and work. Similar attention made other women in this study feel noticed, "*comfortable*" and "*care[d]*" about. Women also appreciated when faculty acknowledged their needs, one example being a faculty who "*emailed all the girls in his class to*" offer an apology about a sexist joke that was made in his class. When discussing this incident in one of the focus groups, women agreed that it was events like these that were particularly important for how they felt about the program in general.

Apart from providing emotional support, faculty provided academic or programming support through office hours and email. Some of the faculty were seen as "*master teachers*", who made CS classes approachable and contributed to these women's growth. Others provided good resources and helped the women envision their success. Women also found it supportive when their class feedback on those aspects that made a class inaccessible to students with no prior experience was acknowledged.

**The Role of Clubs.** Several clubs and organizations also emerged as important for women's persistence in the major. Some of these clubs were located inside their CS department, such as the Association of Computing Machinery – Council on Women in Computing (ACM-W) and Linux Club, while others were university organizations, such as the University Ambassadors program, Honors Program and or the Outdoor Activities Program. Programs outside their department provided support by allowing them to have work-life balance, securing priority registration through the Honors Program, or providing them with financial support, networking opportunities and so on. As an example, two women worked for the University Ambassadors, which provided them with a scholarship and it created a lot of opportunities for their "*professional growth*", "*networking*" and or a "*better perspective*" of the field.

Inside the major, several women felt that the Free Software and Linux Club represented somewhat of a gateway into the "*true*" CoP inside the major, where they could "*improve their knowledge*" while thinking about "*different ideas, instead of just basic stuff*". Four women also mentioned ACM-W, or as they colloquially referred to it "*Women in CS Club*", as important for their persistence. These women found the club to be a "*big support*", as it often taught them how to survive within this environment dominated by men, while also having opportunities to practice interview skill, networking or having "*somebody to talk to*". In other words, by providing access to the more experienced women in the program, ACM-W served as another gateway to the much-needed support.

**Tutor Support.** Tutor lab was a support group organized by the department, where senior CS students helped novice CS students with their homework and coding issues six days a week. The women described the lab as an "*unstructured*" type of support where you

*“could just go in and ask a question”*. For many women in our sample, the support of the tutors was *“the only reason”* they persisted during their first year of their studies. In other words, tutor support was crucial for these women’s enculturation into the program. The extent to which the tutor lab was used varied, but all women agreed that the tutors were a *“good resource”* which *“help[ed] a lot”* whenever they got *“frustrated”* or *“confused”* during their initiation into the program. Jane, for instance, testified that going to the lab *“as a freshman or sophomore”* *“was [a] huge”* factor influencing her retention, both academically and emotionally.

### Practices

In search of Practices that influenced retention of women in this study inside the major, themes that emerged from the data were: Gaining Legitimacy, Establishing Balance, “Lone Wolf”, Finding a Job, Proving You Belong, Abandoning Perfectionism, Finding Online Resources and “Just a Really Good Class” (see, Table 3 for frequencies). In this section, we provide a thorough overview of the most frequent practices and a brief overview of the rest.

**Gaining Legitimacy.** The most prominent practice that emerged as important for women’s retention was the act of gaining legitimacy. What this means is that situations in which women felt acknowledged were crucial for their persistence in the major. We found two sources of legitimacy in our data: inside their major and at work.

As expected, women gained legitimacy inside the CoP of their major from their peers and faculty. The following excerpt describes one such act of acknowledgement:

A lot of students are just like, “Savannah knows the answer.” I don’t always know the answer (. . .), but (. . .) It makes me feel good (. . .) that people see me as someone that they can ask questions to. (. . .) and it just makes me feel like I belong; like my peers have recognized me as someone that they can go to.

In this case, Savannah was legitimized by the men who were her peers, who perceived and publicly acknowledged her as a competent member, someone who could give valuable advice and feedback. Other women mentioned similar examples of being *“recognized”* after winning programming competitions. As a result, they felt more accomplished and more *“excited”* about the program.

Another source of legitimacy came from their work CoP. The fact that their bosses and co-workers acknowledged them as valuable members of the community, while at the same time exposing them to authentic practices, proved to be a huge source of confidence and sense of belonging. The following quote describes one such dynamic:

He’s super supportive, and he believes that I can do things. (. . .) For example, he just asked me to—write unit tests. I was kind of like, “I have no idea what unit tests are”. He told me, “Well, just get started and we’ll see how it goes.” (. . .) Just his faith in me helps me believe in myself,

For Shelby, it was important to get acknowledged as a programmer and a problem-solver at work, because it allowed her to approach work with confidence. Other women reported such acts being influential on their sense of self, and helping them feel *“capable”*. Similar sources of legitimacy were acts of getting a job offer, and/or an offer to stay at the company after finishing their internship.

Interestingly, gaining legitimacy was perceived as a bidirectional practice, one where it was equally important to get acknowledged by others and feel legitimate within oneself. In other words, receiving legitimacy from others was not enough to develop a sense of competency. They also needed to recognize oneself as competent, which was not always easily achievable. The following excerpt illustrates this bidirectionality:

If I think I did a good job, then that's [more] meaningful to me than like a professor saying "Oh! You did a good job!" 'Cause they don't really know me. (. . .) when I feel like I did a good job or when I feel like I belong that's the most powerful. Just knowing that I gave my best, not thinking like "Oh, I could have spent more time on that!" Just knowing "Oh, that was the best work I could have done!"

In other words, for Jane validation from others was not as meaningful as when she herself was pleased with her own performance. Similarly, other women reported feeling as legitimate members when they "*got a good grasp*" of the matter, they "*ma[d]e it through classes*" and or they themselves "*felt good about*" their progress. One common strategy many women used to feel good about their competence was to provide help to others. Jane, for instance, helped "younger" students, because it helped her realize how many "*useful things*" she learned. In other words, such acts helped her realize that she was no longer on the periphery of the CoP and could support others within the community. Many of the women in our sample reported investing time to make "*the experience better for other people*" as that gave them a sense of "*doing well*" in the program and or it helped them deepen their own knowledge.

**Establishing Balance.** The majority of the women in our study described their initiation into the program as a "*blu*", "*devastation*" or a very "*rough patch*" where they had to work a lot to maintain good grades. After initially struggling with work overload, most women realized that they needed to adopt a practice that allowed them to have work-life balance. This practice, consequently, contributed to their retention in the program.

A few women, for instance, purposefully had a minor in a CS-unrelated field, such as German, Business, American Sign Language (ASL) or Psychology. Such a minor provided them with "*kind of like a break*" from all the "*difficult*" CS classes, or it helped them find more friends who were women. As Erin said, it helped her "*even [herself] out*" and not be overwhelmed by their CS major that is dominated by men.

Another strategy these women used that helped them establish work-life balance was to consciously reserve time for non-school related things, such as sport, religious activities or rest. For instance, Monica felt that a balance of physical, social, and spiritual needs was crucial for her persistence in the major, in addition to being a good student. Beatrice reported how "*go[ing] to extreme*" with school work caused her to "*burn out*" and lose motivation, which is why she worked hard on having "*moderation*" in everything she did.

Many women also talked about scheduling "*free*" or "*down time*" in addition to homework and study time. Whether this meant having time to relax, socialize or watch TV, having such time reserved allowed them to "*get [their] mind off of*" school, "*destress*" and achieve work-life balance. As a result, they felt that "*down time*" increased their productivity in the long run.

**"Lone Wolf".** Many women in this study described their approach to learning as independent. They described themselves as "*self-learning*", "*self-teaching*", "*independent*", and or "*self-sufficient*" "*lone wol[ves]*" who "*don't do a lot of people*". Some women believed

that group work took away from their learning experience. Others found learning more gratifying when independent. However, it is important to point out, that even though the “lone wolf” approach was popular, it did not exclude the need for social interactions. This is illustrated in the following quote from Joana:

I do have a few people that (...) I try to be friends with (...), but I don't depend on them, because I've tried that, like ... working always at the same group and getting through a class together and I feel like that's not for me. Mostly because I like to figure out the solutions by myself ... (...). But sometimes I just get stuck on some point in the semester, I get stuck and I feel like I have a few friends that I can reach out for and be like “oh! Can I work with you guys?”

As we can see from this excerpt, Joana believed she “*learn[ed] more*” when she worked independently, she still used available social support when needed, which was true for most other women in our sample.

**Finding a Job.** As internship was not required by the CS program that the women attended, all the positions that they attended during their CS studies will be referred to as a “job”. Most women found a CS job early in the program, which often started as a summer job and then turned into a part-time job for the duration of their studies. According to these women, this practice was very important for them to “*stick with the program*”, as it gave them an opportunity to gather explicit knowledge about the field (as opposed to tacit knowledge they got inside the major). In her interview, Maggie explained how and why the learning experience in her first job was different from her learning in school:

I'd never seen a program longer than a hundred lines of code, and now I'm looking at thousands, and thousands, and thousands, all merged together, in one huge project. So, I spent a while just wrapping my mind around that (...) A lot of words, I did not understand in the code ... like 90% of what was said went over my head. So, there was a few meetings I had, just one-on-one with my hiring manager that I literally just asked him vocabulary questions. ... But, there were things like ... I had to learn a new programming language, and a different operating system. ... So, I don't know ... I think there was just a lot of different varieties of learning, and I think that's why I enjoyed it so much, because I wasn't just learning one track the whole time. I was learning all sorts of different new skill sets.

In other words, Maggie felt that she was exposed to authentic learning opportunities. She was able to see how “*real world*” code looked, and she was able to study, talk about and build on the code. Other women also reported learning “*a lot*”, sometimes even taking “*control of [their own] learning*” by instigating projects of their own interest, which in turn enhanced their learning inside the major. All the women reported that the knowledge they gathered at work gave them an advantage in school both in terms of performance and competence.

Another benefit of finding a job was that it helped them envision what it would be like working in CS industry, or what kind of job they would enjoy the most. For instance, Monica explained how one of her first work projects positively influenced her retention by helping her realize which aspects of a job (e.g. leadership, communication) were important and attainable for her. Other women reported liking the “*social*” aspect of their job, the “*welcoming*” environment, and the feeling of being “*included*”.

**Proving You Belong.** Even though it only showed up in 7.4% of the codes, this practice was important during the enculturation into the CoP period. Many women testified that

they felt the “*pressure to be the best*”, outperform men, “*work harder*”, “*learn more*”, “*dig deeper*” and or “*study harder*”, so they could “*get to the same point*” as the men in their classes, whom they perceived as someone who had been coding for their whole life. Efforts to prove themselves included working on “*get[ting] better grades*” and or working on “*get[ting] all As*”. One woman openly confronted anyone who doubted her and or her right to be part of the program, while another waited on “*very hard problems*” to solve on the board in front of the whole class. Similar to legitimacy, this practice was bidirectional, as women felt an equal need to prove to themselves as they did to others that they belonged.

**Abandoning Perfectionism.** In about 6.8% of the codes, we found evidence that all women reached a milestone at one point in their CS program, when they realized that they needed to abandon their need to *Prove they Belong[ed]* as it was counterproductive to their persistence in the program. Even though abandoning perfectionism was hard to do, all women agreed that once they managed to let go, they actually developed a stronger sense of belonging to the program. As an example, Shelby talked about getting a B in Physics, which ruined her “*perfect*” 4.0 GPA, but was liberating, as it put things into perspective in terms of what mattered and what did not “*really matter anymore*”. Another example is provided by Jane, who talked about the significance of allowing herself to withdraw from a class, even though it was “*too late*” in the semester, as she realized that despite not knowing every single programming language, she was “*still a computer scientist*”.

**Finding Online Resources.** Finding Online Resources (5.6% of the codes) was a practice that required a high degree of skill to master and was characterizing their experience in the beginning of the program. In both focus groups, women agreed that developing ability to locate, evaluate and utilize online resources was one of the most important practices for ongoing participation, one that was neither overtly seen nor specifically taught in their CS program. Though no one mentioned what it took to acquire such skill, all women reported relying on the Internet to find answers, do research and reach out to online programming communities. For some, this skill translated into learning how to “*ask the right questions*” both online and in person, while others called themselves “*stackoverflow-sufficient*”, especially in their upper level classes (Note: Stack Overflow is an open online community for people who code), which basically meant that they relied on support from online communities, such as Stack Overflow, when it came to doing homework.

**“Just a Really Good Class”.** In most participants’ journeys, at least one CS college-level class emerged as pivotal at one point in their education (5.3% of the codes). The ways in which classes influenced women’s persistence were multifaceted and they ranged from helping women gain confidence in their CS competence to helping them visualize “*how it’ll be in an actual job*” in the industry. As an example, some women reported that certain classes served as good platforms for their skill acquisition and or provided moments of clarity on their way to gaining competency in the field. Other women mentioned classes where they learned “*something different*” and “*very useful*”, or classes that were simply “*cool*”, For many “*everything else buil[t] from*” such classes, while others considered those classes to contribute to them being a “*little bit more in love*” with CS.

## Discussion

This study focuses on examining retention of women in CS majors through the lens of LPP within CoPs (Lave, 1996, 2009; Lave & Wenger, 1991, p. 2011; Smith, 2009; Wenger, 1998a, 1998b, p. 2000, 2009; Wenger et al., 2002; Wenger-Trayner & Wenger-Trayner, 2015). More specifically, we examined different types of social interactions and practices that provided context for ongoing participation of these women in their CS major.

### *Social interactions*

Upon examining the reported interactions inside the CS major that supported retention, four categories of supportive interactions emerged. In many ways, these findings align with previous literature, but they also add nuance to the understanding of those interactions that directly support retention from the perspective of LPP in CoP, such as how interactions support legitimacy (Wenger, 1998b) or how they provide opportunities to interact with more seasoned members of the community (Rogoff, 2003).

Peer support was found to be the most frequent type of social interaction supporting retention inside the major and most women reported relying on peer support for different educational and emotional reasons. Women did not report preferring one type of interaction over another, neither did they mention the importance of peer gender, which is contrary to literature that often suggests men who are peers negatively influence retention (e.g. Barker et al., 2009; Benbow & Vivyan, 2016; Bunderson & Christensen, 1995; Clegg & Trayhurn, 2000; Gokhale & Stier, 2004). We did find several incidents of sexist remarks from men who were peers, but since these were not within the scope of the study, it is not clear whether they were as widespread as suggested in literature (e.g. Barker et al., 2009; Benbow & Vivyan, 2016; Bunderson & Christensen, 1995; Clegg & Trayhurn, 2000; Cohoon, 2001; Gokhale & Stier, 2004; Güner & Camp, 2002). It is also possible that women who persist are not fazed by negative remarks, as suggested by some of the women in our study.

Interactions with faculty were also found to be important for women's persistence in CS, both educationally and emotionally. This finding provides insights to the types of faculty support that increase retention (e.g. interactions that provide legitimacy), which is rarely investigated in literature (e.g. Ceglie, 2009; Cohoon, 2002a, p. 2006), as literature often focuses on faculty interactions that deter women from CS (e.g. Barker et al., 2009; Benbow & Vivyan, 2016; Bunderson & Christensen, 1995; Denner et al., 2014; Gokhale & Stier, 2004; Kapoor & Gardner-McCune, 2018; Medel & Pournaghshband, 2017; Singh et al., 2007; Varma & Hahn, 2007).

Using the theoretical lens of LPP in CoPs also allowed us to look into the benefits of those interactions that happen at the level of embedded subcommunities (Lemke, 1997). In addition to the importance of different CS and university clubs (e.g. ACM-W, the University Ambassadors), we found evidence about the importance of the CS Tutor Lab to the initiation of new members at the periphery (Lave & Wenger, 1991) of the CoP of this major. All women reported using the help of tutors in the first few semesters, which was crucial for their retention upon joining the major. The help received was mostly academic, but some examples of emotional support were also recorded. We know from research (Biggers et al., 2008; Miliszewska et al., 2006; Stephenson et al., 2018) that participation at

the periphery is the most problematic in terms of attrition. Therefore, our findings imply that purposeful use of tutoring programs could increase retention of women in those critical semesters. While some researchers emphasize the importance of tutoring labs for the retention of women and minorities (e.g. Binkerd & Moore, 2002; J. Brown et al., 1997; Miliszewska et al., 2006; Nett, 2008), studies on the influence of tutoring on women's retention are rare (e.g. Cottam et al., 2011; Loos et al., 2005; Miliszewska et al., 2006; Staehr et al., 2000). More research is needed to understand the role of tutoring on the persistence of women in CS major, as well as what kind of tutor support is most important for retention of women in CS. Similarly, we need more research on the importance of different subcommunities (e.g. clubs) that support retention, which the scope of our study did not allow us to investigate fully, even though we got some indications of their importance.

### **Practices**

All reported practices were examined to identify practices inside the CS CoP which supported these women's retention inside their CS major. Nine practices emerged, four of which were frequently experienced throughout the major and four of which were more present at the periphery of their participation.

The most frequent practice that emerged was Gaining Legitimacy. This practice occurred both inside their major and at work. Receiving legitimacy in school made women more excited about the major, while receiving legitimacy at work helped them feel like programmers. At the same time, gaining legitimacy helped the women in this sample develop a sense of belonging and it contributed to their overall positive experience. These findings are aligned with the theoretical framework of LPP in CoP (Lave & Wenger, 1991; Wenger, 1998b, 2010), which posits that when learners are acknowledged as competent by more experienced members of the community, they can develop a sense of belonging. Sense of belonging is a precursor of retention (Lave & Wenger, 1991) and its influence on retention has been researched by many (e.g. Blaney & Barret, 2022; Blaney & Stout, 2017; Sax et al., 2018). In addition to gaining legitimacy from others, we found that the women in our study needed to acknowledge themselves as competent. This bidirectional aspect of legitimacy is surprising. While several authors posit that learning, participation and identity formation from the perspective of LPP in CoP are co-constructed and negotiated between the community and the individual (e.g. Buysse et al., 2003; Dawson, 2013; Holmes & Meyerhoff, 1999; Jacoby & Ochs, 1995; Laxton & Applebee, 2010; Wenger, 2000, 2010), we only found one author who argues that legitimacy is also co-constructed (Back, 2011).

Another practice that emerged as very important for the retention of women in CS was the practice of establishing (school) work-life balance. Women achieved such balance by enrolling into a CS-unrelated minor or by approaching schoolwork in moderation, while combining it with a balance of other aspects of life, such as religion, sport, social life and or relaxation. Even though work-life balance is something that we all strive towards in our own personal lives, this practice was rarely cited in literature as important for retention of women in CS (e.g. Beyer, 2014; Beyer et al., 2005; Frieze & Quesenberry, 2015). For that reason, we believe that further research is needed on the relationship between work-life balance and retention in CS.

In addition to relying on tutor, faculty and peer support inside their major, most women in this study described themselves as having an individualistic (“lone wolf”) approach to learning, either due to their personality and or their beliefs. This is similar to Callahan and Tomaszewski (2007), who found that in addition to sisterhood, individualistic engagement was one of the two ways women working in a CoP dominated by men interacted inside the community. At first glance, one may conclude that this finding confirms the stereotype that computer scientists are asocial, isolated or socially awkward (e.g. Beyer, 2014; Cheryan et al., 2013; Fisher et al., 1997; Margolis & Fisher, 2003; Mercier et al., 2006). However, we want to emphasize that our study is not confirming such a stereotype. On contrary, even though most women in our study had a strong preference for the “lone wolf” approach to learning, they also greatly benefited from social interactions and in fact relied a lot on both emotional and academic support from their peers, faculty, tutors and other people at the university.

The final wide-spread practice that positively influenced retention of these women was the act of finding a CS-related job while still being a student in the program. Work experiences helped the women learn new skills, benefit at school, envision themselves in the field and or develop a sense of belonging. This is an important finding, as it suggests a concrete measure CS programs can put in place to support retention of women in CS. At the same time, it provides empirical evidence for multimembership (Lemke, 1997), an important concept from LPP in CoP framework, which suggests that to develop true mastery of practice, it is often necessary to participate across different CoPs. However, apart from Kapoor and Gardner-McCune (2018) who found that positive experiences with CS internships positively influenced persistence of women in the major, there is very little research investigating the relationship between work experiences and retention of women in CS. More research is needed to confirm the relevance of multimembership on retention of women in CS.

Finally, we found four practices that were relevant at the periphery (Wenger, 1998b) of their enculturation into the program: the bidirectional practice of proving you belong inside this community, the act of abandoning perfectionism, learning how to find online resources and finding a really good class that kept you motivated. Bidirectional practice of proving you belong may be related to one of the key characteristics of CoPs (Wenger, 1998b). Wenger (1998b) said that there has to be a substantial overlap in participants’ descriptions of who belonged in a CoP, an overlap that had historically been lacking in CS majors, as women were found to leave because they didn’t feel welcome or didn’t feel like they belonged (e.g. Barker et al., 2009; Benbow & Vivyan, 2016; Bunderson & Christensen, 1995; Clegg & Trayhurn, 2000; Gokhale & Stier, 2004). Finding that women who persisted in CS practiced active and passive strategies to resist the imposter syndrome (Clance & Imes, 1978) at the beginning of their program is important when designing programs to support women during their enculturation period, especially considering studies that highlight the importance of family support (Blaney, 2021; Sax et al., 2018), incoming sense of belonging (Blaney & Barrett, 2022) and other factors CS programs have little control of.

Interestingly, we also learned that these women’s understanding of CS competence was initially skewed by lack of experience within this field. According to Wenger (1998b, 2000), competence is not a display of socially constructed knowledgeability, but it consists of individual’s ongoing and changing experience and it differs from one person to the next. We learned that once the women developed a deeper understanding of what it

means to be competent in CS, they abandoned the tendency to strive for perfectionism. This was described as a pivotal moment in their retention and to our knowledge, there are no studies that examine this practice. Similarly, we did not find any studies that researched the importance of developing the skills to find online resources. As far as finding a really good class which supported these women's retention, this we explain using the LPP in CoP. The classes that women describe as pivotal for their retention allowed them to perceive an alignment between the instruction and the broader CS CoP (Lave & Wenger, 1991), or they were perceived as authentic because both their topics and assessment were aligned with what was taught (Shaffer & Resnick, 1999). Exposure to authentic activities in authentic practice is central for learning (Brown et al., 1989), according to the theoretical perspective used in this study. It is also something that a lot of CS courses struggle with (Guzdial & Tew, 2006).

### **Limitations and future work**

This study has several important limitations which need to be considered. To begin with, the sample for this study has been drawn from a single university in the Intermountain West, which affected the sample in several different ways. For one, some of the findings might be specific to the culture of the Intermountain West, which is predominantly Caucasian (U.S. Census Bureau, 2017). In addition, this area of the US has a growing start-up and tech community, which might have influenced these women's accessibility to employment, as the supply of CS graduates is not fast enough for the growing tech industry in the area (Urian, 2021). It would be important to investigate if women's retention in other areas is also influenced by this practice. Second, due to a small number of women in upperclassman standing, we collected data from both Juniors and Seniors, but Seniors had richer stories to share. Future studies, therefore, should focus on a more diverse sample of Senior women.

Next, while there are many studies focusing on the gender gap (e.g. Ashcraft et al., 2012; Denner et al., 2014; Fisher et al., 1997; Gürer & Camp, 2002; Liu & Blanc, 1996; Margolis & Fisher, 2003; Margolis et al., 2000; Ragsdale, 2013; Singh et al., 2007), none of them examine the experience of successful men in CS. Therefore, there is no benchmark to compare our findings with and we do not know if factors that influence women's ongoing participation are exclusive to women or are similar for retention of all students in CS.

Finally, this study was designed to look at retention inside the CoP of these women's CS major primarily focusing on practices and social interactions inside the major. Such approach provided a limited insight into how multimembership (Lemke, 1997) affected their retention. Even though we have some insight into the role of work CoP, there are indications of the importance of the online CS community and other external communities that need to be further explored in future research.

### **Implications and conclusion**

Studying retention of women in CS from the perspective of LPP in CoPs has several important implications for CS departments as they strive to broaden participation of women in CS majors. To begin with, this study reveals the importance of building

a community inside the CS major where educational and emotional support among peers, and among students and faculty is cultivated and encouraged for the benefit of all women struggling to persist in this major. It is also important to organize subcommunities that would support newcomers at the periphery. This support could be educational through Tutor Labs and or emotional through clubs for women (aka ACM-W). Another potential intervention that could support retention of women is a network of mentors, as is sometimes done for new faculty members (e.g. Mullen & Hutinger, 2008), where more seasoned members of the CoP (aka mentors) are assigned to newcomers as support and encouragement. Several of the women in my study reported benefiting from peer and faculty mentors that they self-identified. It is our belief that a more formal structure would have the potential to make an even greater impact.

In terms of practices that support retention, we learned that different practices support retention during the enculturation period (aka at the periphery of the CoP), some of which point out the importance of well-designed courses, especially in terms of how authentic the learning opportunities are that they offer, the importance of explicitly teaching the skills of finding online resources and the importance of teaching women what knowledgeability looks like in this field.

When it comes to practices that supported retention throughout the program, finding a job, for instance, was found to both provide legitimacy and a sense of belonging. CS programs could easily develop and adopt mechanisms that encourage women to search for a job early in the program, while at the same time serving as brokers (Wenger, 1998b) who create bridges with those companies that other women had a positive experience with. Similarly, faculty could be instructed to consciously offer legitimacy, while work-life balance could be supported with better course design.

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## ORCID

Katarina Pantic  <http://orcid.org/0000-0002-5462-1772>

## Data availability statement

The data that support the findings of this study are available from the corresponding author, [KP], upon reasonable request.

## Subject classification codes

: include these here if the journal requires them

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