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Gender and the pipeline metaphor in computing

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Using the pipeline metaphor as the conceptual framework, the current paper presents gender differences in computer science (CS) and computer engineering (CE) students' study aspirations in elementary and high schools, the extent to which they hold a study-related job while in college and their career aspirations after graduating from college. It highlights some of the weak joints of the pipeline and suggests a number of implications to improve representation of women in computing field. It is based on 150 interviews with undergraduate male and female students belonging to five major ethnic/racial categories (White, African-American, Hispanic, Asian American, Native American) from seven institutions in the USA.

Keywords: attrition; ICT; leaky pipeline

1. Introduction

The science, technology, engineering, and math (STEM) career track from elementary school to initial employment has been depicted as a pipeline. It is generally believed that if a sufficient number of women are encouraged to pursue sciences and mathematics in their elementary and high-school years, exposed to technology early on, and persuaded to enter science and engineering programmes in college/university, the gender disparities now present in STEM would disappear. However, women's percentages in STEM decrease as they progress through the pipeline. Men, for the most part, travel smoothly from the beginning to the end of the pipeline and thus dominate STEM. The pipeline is said to be leaky – there is steady attrition of females at every level of STEM, from elementary school into the workplace, in most industrialised countries around the world (Clark 2005).

The current paper focuses on the pipeline metaphor as it applies to the computing field mostly for two reasons. First, ideologically better representation of women in computing field is an issue of gender equity and fairness. As Western countries have entered the information era, more women than men have become under-represented in computing education and occupations (Pisimisi and Ioannides 2005). For instance, only one-sixth of information and communication technologies (ICTs) employees were women in EU in 2004. Furthermore, there is an actual fall in the proportion of female computing graduates – from about 25% in 1998 to only about 22% in 2006 (Reding 2007). Similarly, women comprised only 27% of computer/mathematical scientists in the USA

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in 2004. Furthermore, the percentage of women in mathematics/CS occupations declined about two percentage points between 1993 and 2003 (National Science Board 2006).

Second, practically inclusion of women in computing field is an issue of meeting the growing workforce needs in the high-technology sector. Computing knowledge is used in most sectors in Western countries and is not limited to just the ICTs industry itself. There is a growing perception among business leaders and government officials in Western countries that high-technology sector is facing a shortage of qualified people in computing field. According to Viviane Reding (2007), European Commissioner for Information Society and Media, there will be a shortage of 300 000 qualified staff in ICTs sector in EU by 2010. To deal with the shortage of skilled labor, the USA has instituted a temporary foreign workers programme (65 000 per year since 1990, with the exception of 115 000 per year from 1999 to 2000 and 195000 per year from 2001 to 2003). Over half of temporary work permits (56.8%) has been going to computer-related occupations (National Science Board 2006). It is, therefore, no surprise that most industrialised countries are trying to tap women in computing field to compensate for the expected shortfall of candidates from the traditional source – the male population.

Literature on why pipeline is leaky in educational and work settings in computing field can be grouped into three areas. First, the limited access and the differential use of computer technology in early school years ends up contributing to unequal participation of girls in computer science (CS)/computer engineering (CE) education in colleges/universities. A survey in the USA revealed that the middle- and high-school female students viewed 'a computer person as a male and anti-social' and thus they wanted to purse those fields where they could make a difference (American Association of University Women 2000). A study carried out in primary school in Denmark found that boys tend to dominate computer use, and thus leave girls behind (Elkjaer 1992).

Second, cultural factors that reinforce the masculine image of computers and economic factors that make it hard for women to continue in the computing field at the college level. A study of college students in Norway found that the male culture made computing a difficult subject for female to study (Kvande and Rasmussen 1989). Another study in the UK found that courses in the ICTs to be rather narrow covering only technical subjects rather than being broad including social issues to retain women in the program (Bissell *et al.* 2003). US women end up leaving CS/CE major before graduation because they face difficulty in managing hard course work, family obligations, and job commitments (Varma 2007a, Varma 2007b).

Finally, male organisational culture, demanding workload, and frequent conflict between professional work and family life make ICTs less attractive to women. A survey carried out in Australia revealed that women in ICT professions faced difficulties on adapting to a masculine organisational culture (Pringer *et al.* 2000). Another study carried out in Germany found lack of compatibility between professional life and family life for women in ICT professions (Menez *et al.* 2001). The Strategies of Inclusion: Gender and the Information Society (SIGIS) project conducted in several European countries found a serious 'leaky pipe' problem within the core ICTs mostly owing to 'chilly' occupational cultures and workplace practices (Faulkner *et al.* 2004).

It should be noted that the concept of pipeline in computing field has been criticised. It assumes a rather sequential path with education on the one end and work on the other. In reality, education and training play several diverse roles in scientific preparation of people. There are many different pathways, including a non-traditional pathway, to a computing career (Bartol and Aspray 2006). Also, a focus on the supply side tends to neglect analysis of the demand side, especially organisational resistance to change and the persistence of barriers to entry of women into the scientific professions (Varma and Hahn 2007).

As yet, there have been very few empirical studies conducted directly on the dynamic referred to in the pipeline metaphor; most studies either address issues related to under-representation of women in computing field to point out the problems with the pipeline metaphor or limit their focus on the state of affairs at a given stage of the pipeline. This paper analyses differences between female and male students from different ethnic/racial groups in computing programmes with respect to the pipeline metaphor. To reflect the transition from one stage to another in the pipeline metaphor, it tests the following hypotheses:

- H_1: Female and male students will differ significantly in elementary school in their career plans.
- H_2: Female and male students will differ significantly in high school in their career plans.
- H_3: Female and male students who hold jobs will differ significantly in the degree to which their job is related to computing field.
- H_4: Female and male students will differ significantly in their decisiveness in following a career in computing field after completing their undergraduate education.

2. Data collection and analysis

An empirical study was conducted with undergraduate female and male students who were majoring in a CS/CE field in the USA. It was carried out in seven institutions that granted undergraduate degrees in one or more CS and/or CE programmes and were designated as Minority Serving Institutions – a category of educational establishments such as Hispanic-Serving Institutions, Historically Black Colleges and Universities, and Tribal Colleges and Universities. The data were gathered in 2004–2005 through face-to-face interviews as part of a larger project on women in CS/CE education. The technique of interviews was considered useful primarily because there is little information on the barriers women in different ethnic/racial groups face in pursuing CS/CE education in Minority-Serving Institutions. Interviews were conducted with 150 students, divided into groups of 30 (15 female and 15 male) belonging to one of the following five major ethnic/racial groups: White, African-American, Hispanic, Asian American, and Native American. These sessions involved using interview guides, asking same 61 open-ended questions, recording the answers, and following up with additional relevant questions or probes. To ensure that data collection is consistent, Roli Varma, principal investigator on the project, conducted all interviews. Students interviewed were in their second and third years of CS/CE study. Random sampling was used to select subjects on sites with sufficient numbers of female and male students; however, purposive sampling was used at sites lacking sufficient numbers of some groups (e.g. Native Americans) majoring in CS/CE. This sample made it possible to analyse the specific situations of female and male students from different ethnic/racial groups.

Ten out of 61 questions provided the specific data on the pipeline metaphor. A content analysis coding scheme was developed to assess students' career paths while in elementary school, high school, and university. Two independent trained coders coded the interviews to ensure consistency and objectivity. The following terms were operationalised:

(1) Early career aspiration was any comment about science, non-science, or undecided field when student was in elementary school. Example: 'Just something to do with science or technical stuff'. = Career in a science field. 'I wanted to be many things, a writer, a singer, and an actress' = Career in a non-science field. 'Gosh, in elementary school, I never thought of it'. = Undecided.
(2) Middle career aspiration was any comment about science, non-science, or undecided field when the student was in high school. Example: 'Computer science. At the end of high school I had taken some computer science classes. = Career in a science field. 'I was going to go into the broadcasting field like a cameraman or something like that'. = Career in a non-science field. 'There wasn't really anything specific'. = Undecided.
(3) Relation between job and undergraduate studies while in college was any comment about a job related to CS/CE or job unrelated to CS/CE field. Example: 'I am working at my church.

We are implementing a network system and we are buying management software'. = Job related to CS/CE. 'I have two jobs. On weekdays, I work for Pizza Hut. On weekend, I cut coconuts in the flea market'. = Job unrelated to CS/CE. Student who did not hold any jobs while going to college were put into the third category of no job.

(4) After college career aspiration was any comment about joining the workforce, pursuing graduate studies, or no idea. Example: 'I want to work for some company, for instance, Hewlett Packard or Compaq for a year to two just to see what is out there for computer scientists' = Joining workforce. 'I want to do Master's and hopefully PhD someday'. = Pursuing graduate studies. 'I haven't really thought that far ahead'. = No idea.

The cross-tabulation function of SPSS version 14.0 was used for testing the significance of the differences in the perceptions of male and female students (H_1–H_4). Statistical testing was based on Pearson Chi-square or X^2 test. Hypothesis testing was not done for ethnic/racial groups because of the small number of cases; 15 subjects in each ethnic/racial group are likely to show significant results only if the differences are very large. Subjects from major ethnic/racial groups are included mostly because often studies make claims about women in general even though their sample is limited to White women. However, significant results for differences between female and male students in the ethnic/racial groups are reported.

3. Findings

3.1. *Students' early career aspirations*

For students' early career aspirations, two questions were asked: When you were in elementary school, what profession did you want to pursue? When you were in high school, what profession did you want to pursue? Their responses were crosschecked with four additional questions: What was your best subject in elementary school? What was your worst subject in elementary school? What was your best subject in high school? What was your worst subject in high school? Students' responses were coded into three categories: science, non-science, and undecided since it is generally believed that students' early interest in a science-related field is likely to lead to a major in a CS/CE field later in college.

The first two hypotheses predicted that female and male students would differ significantly in elementary school and in high school in their career plans. Table 1 gives small X^2(0.771 for H_1 and 2.079 for H_2, df = 2), which indicates that female and male students did not differ significantly in respect to their career aspiration neither in elementary school nor in high school. H_1 and H_2, therefore, are not supported. However, the career aspiration differences between elementary school and high school for the female and male students show rather interesting results. For example, there is a 21% increase in interest in science, a 20% decrease in interest in non-science, and a 1% decrease in undecided categories for female students from elementary to high school. It indicates that an increased interest in science is mostly due to a decreased interest in a non-science field. In comparison, an increased interest in science for male students from elementary to high school (+20) is mostly owing to a decrease in being undecided (−12%), rather than a decreased interest in non-science (−8%).

A breakdown of male and female students in different ethnic/racial groups shows similar results, with few variations. White, Hispanic, and to some extent Native American female students show an increased interest in science along with a decreased interest in a non-science field. For African–American female students, however, an increased interest in science was due to a decreased interest in both a non-science field and being undecided equally. Asian American female students showed no change in their interest in a science field, and a decreased interest in a non-science (−7%)

Table 1. Students' career interests during elementary and high schools.

	Interest in field	Female (% among careers)			Male (% among careers)			Total (% among careers)		
		ES	HS	Dif.	ES	HS	Dif.	ES	HS	Dif.
Overall	Science	40	61	21	39	59	20	39	60	21
	Non-science	45	25	−20	41	33	−8	43	29	−14
	Undecided	15	14	−1	20	8	−12	17	11	−6

Statistical significance H_1: ns; $\chi^2 = 0.771$, df $= 2$; H_2: ns; $\chi^2 = 2.079$, df $= 2$
ES: Elementary school, HS: high school, Dif: difference between ES and HS

Ethnicity of respondents	Interest in field	Female ES	Female HS	Female Dif.	Male ES	Male HS	Male Dif.	Total ES	Total HS	Total Dif.
White	Science	33	67	33	40	60	20	37	63	26
	Non-science	53	17	−37	20	27	7	37	22	−15
	Undecided	13	17	3	40	13	−27	27	15	−12
African-American	Science	47	60	13	47	53	7	47	57	10
	Non-science	27	20	−7	40	47	7	33	33	0
	Undecided	27	20	−7	13	0	−13	20	10	−10
Hispanic	Science	33	60	27	33	27	−7	33	43	10
	Non-science	67	33	−33	53	73	20	60	53	7
	Undecided	0	7	7	13	0	−13	7	3	−3
Native American	Science	33	67	33	33	73	40	33	70	37
	Non-science	47	27	−20	47	20	−27	47	23	−23
	Undecided	20	7	−13	20	7	−13	20	7	−13
Asian American	Science	53	53	0	40	80	40	47	67	20
	Non-science	33	27	−7	47	0	−47	40	13	−27
	Undecided	13	20	7	13	20	7	13	20	7

field was the same as the increase in being un-decided (7%). As for males, all ethnic/racial groups showed an increased interest in science (20% for White, 7% for African-American, 40% for Native American, 40% for Asian American) except for Hispanic students, in which the interest in science decreased by 7%. The increased interest in science for White and African–American male students mainly came from being undecided, whereas for Native American and Asian American male students it came from non-science. Hispanic male students are rather different from others because they show the largest non-science rate (73%) in high school, which is largely owing to an increase (20%) from elementary school. Also, there are only 27% Hispanic male high school students who chose science, which is the smallest rate of science interest in high school. Asian American males have the highest rate (80%) of science interest in high school, followed by Native American (73%), White (60%), and African-American (53%) males.

3.2. *Students' job activities*

For the relationship between students' job activities and their CS/CE studies, two questions were developed. The first question asked: Do you have a job in addition to going to school? Students' responses were placed into yes and no categories. Students who held a job besides their studies were further asked: Do you think your job relates to your current CS/CE studies, if yes, how? Students' responses were coded into two categories: job related to CS/CE and job unrelated to CS/CE.

The third hypothesis predicted that female and male students who hold jobs would differ significantly in the degree to which their job is related to CS/CE field. Table 2 gives large X^2 (15.875) with small p-value (<0.001) for df $= 2$, which indicates highly significant gender

Table 2. Relationship between job and studies.

		Female	Male	Total
Related job	% within gender	27	60	43
	Adjusted residual	−4	4	
Unrelated job	% within gender	37	20	28
	Adjusted residual	2	−2	
No job	% within gender	37	20	28
	Adjusted residual	2	−2	
Statistical significance H_3:	$p < 0.001$; $\chi^2 = 15.857$, df $= 2$			
Ethnicity of respondents		%within gender		
White	Related job	43	80	62
	Un-related job	21	7	14
	No job	36	13	24
African-American	Related job	25	64	43
	Un-related job	31	21	27
	No job	44	14	30
Hispanic	Related job	7	53	31
	Un-related job	43	20	31
	No job	50	27	38
Native American	Related job	27	47	37
	Un-related job	53	33	43
	No job	20	20	20
Asian American	Related job	33	53	43
	Un-related job	33	20	27
	No job	33	27	30

differences with respect to the students' job characteristics while in college, confirming H_3. Overall 71% of students held a job in addition to their studies. While 80% of men had a job, only 64% of women had a job. Sixty percent of the male students had a job related to their CS/CE studies and only 20% held a job unrelated to CS/CE studies. In contrast, only 27% of the female students had jobs related to their studies, and 37% held jobs unrelated to CS/CE. The adjusted residuals are higher than the threshold of 2.0 for related-job, unrelated-job, and no-job, which means students' gender and job characteristics are likely to be dependent on one another.

A breakdown of male and female students in different ethnic/racial groups exhibits a consistent pattern with H_3. First, male students in every ethnic/racial group have the largest rate in the related-job category; female students in every ethnic/racial group with the exception of White have the lowest rate in the related-job category. Second, within the un-related job category, the rates for females in every ethnic/racial group are greater than those for male students. Third, within the no-job category, rates for females in every ethnic/racial group except Native American are greater than those of their male counterparts.

3.3. *Students' career plans after undergraduate degree*

For students' future career plans after undergraduate studies, one question was asked: What do you want to do after you graduate with a CS/CE degree? Their responses were crosschecked with one additional question: Do you plan on studying for an advanced degree after completing your bachelor's degree? Students' responses were coded into three categories: desire to join workforce, wish to pursue higher education, and having no idea what to do with their degree.

The fourth hypothesis predicted that female and male students would differ significantly in their decisiveness in following a career in CS/CE after completing their undergraduate education.

Table 3. Students' career plans after undergraduate degree.

		%within gender		
		Female	Male	Total
Work	% within gender	76	90	83
	Adjusted residual	−2.4	2.4	
Higher education	% within gender	12	10	11
	Adjusted residual	0.5	−0.5	
No Idea	% within gender	12	0	6
	Adjusted residual	3.1	−3.1	
Statistical significance H_4:	$p < 0.01$; $\chi^2 = 10.234$, df = 2			
Ethnicity of respondents				
White	Work	87	93	90
	Higher education	7	7	7
	No idea	7	0	3
African-American	Work	71	93	83
	Higher education	7	7	7
	No idea	21	0	10
Hispanic	Work	73	80	77
	Higher education	7	20	13
	No idea	20	0	10
Native American	Work	80	100	90
	Higher education	7	0	3
	Idea	13	0	7
Asian American	Work	67	87	77
	Higher education	33	13	23
	No idea	0	0	0

Table 3 gives large X^2 (10.234) with small p-value (<0.01) for df = 2, which indicates that gender affects students' career plans after completion of an undergraduate degree, thus confirming H_4. Over 90% of male students expressed their desire to work, 10% wanted to pursue higher education, and none responded with having no idea. In contrast, 12% of the female students indicated that they had no idea about their future. An analysis of the adjusted residuals also shows that women are significantly under-represented in the work category (−2.4) and significantly over-represented in the no-idea category (3.1).

A breakdown of male and female students in different ethnic/racial groups reveals the same pattern with the H_4. For the no-idea level, the differences between females and males within each ethnic/racial group are very large. For the joining-work level, all of the males have higher rates than the females within each ethnic/racial group. And as for the going-for-higher-education level, the difference between male and female students is not as large as for the no-idea and work levels, but some difference can be found in all ethnic/racial groups.

4. Conclusion

The current paper has addressed the gender differences in the study aspirations of CS/CE students in elementary and high schools, the job characteristics alongside their college studies, and career aspirations after finishing their undergraduate studies. With respect to the evolution to study a science field from elementary to high-school, differences between female and male students were non-significant. However, motivation seems to be different for male and female students. For example, in high school, still more female students were undecided than male students. With respect to the students' job characteristics alongside their undergraduate studies and the desire to take up a career after completing studies, differences were more pronounced. The passage from university to workplace seems to be smoother for male students than for female students. Male students more often have work experience gained during their study and they seem to know what they want to do with their degree.

To support or refute the pipeline metaphor, however, a longitudinal study is needed which would show issues female students face in each stage and in the transition from one stage to another. The current paper has highlighted some of the weak joints of the pipeline metaphor. Yet, it has a number of implications to improve representation of women in computing field. Since female students in most ethnic/racial groups tend to move from a non-science to a science path in elementary and high school, their interest in science does not seem intrinsic and instead it evolves over a time period. It suggests increasing their exposure to computers and engaging them to use computers to solve mathematical problems or simple programming to get them interested in the discipline of CS/CE. The new reality is that students especially minority students must support their studies and family by taking a job during their undergraduate studies. In this situation, the role of advisor becomes rather important. They could guide students' CS/CE curricula based on students' specific situation rather than standard guidelines of their department. Most importantly, female and minority students must know the use value of CS/CE for their future, especially since there is an increasing perception that CS/CE jobs are being outsourced to India and China. CS/CE departments should invite practitioners of CS/CE from the public and private sectors to provide students with information about different CS/CE career options so students know the availability of jobs and salary with a degree in CS/CE.

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