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Bioinformatics as a Means to Attract Women to Computer Science

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Abstract. Programs in bioinformatics, offered in many academic institutes, are assumed to expand women's representation in computer science (CS). Women's enrolment in these programs is high. Our questions are: Do these programs attract different women from those attracted to CS programs? What factors underlie women's decision to enroll in bioinformatics programs? How do these factors differ from those of women who choose CS, if at all? What career opportunities do these women anticipate and pursue? Using questionnaires and interviews, we found a statistically significant difference between the factors that motivate women to choose bioinformatics and others to study CS. Many bioinformatics students did not consider CS as an alternative. Post-facto they learned to love computing, albeit with a biology-oriented purpose. "Computing with purpose" underlies many participants' pursuit of careers in research, CS, and bio-tech. We thus conclude that bioinformatics programs do indeed expand women's representation in CS.

Keywords: higher education, computer science, bioinformatics, women, underrepresentation.

1. Introduction

Studying Computer Science (CS) can serve as a springboard for successfully entering the labor market and pursuing a career in CS and other relevant, lucrative and prestigious areas. Despite that, women in many western countries remain underrepresented in academic CS programs.

Many academic institutes offer programs in bioinformatics – an interdisciplinary field, which combines life sciences and CS. The emergence of interdisciplinary studies, such as bioinformatics, is in line with the increase of applied information technology (IT) fields, in which computational tools are used in the service of human needs (Herring *et al.*, 2006).

In bioinformatics studies students deal with life science issues, such as the genome, drug design, and protein structure, using computing and computational methods. Namely, students study CS integrated with biology and life science issues contextualized in the real world, issues revolving around improving life and helping people (Beck *et al.*, 2007; LeBlanc and Dyer, 2004; Maloney *et al.*, 2010; Tartaro and Chosed, 2015; Tartaro and Cottingham, 2014).

The premise is that bioinformatics programs will stimulate the interest of women in CS and CS-related studies and serve as a motivating factor in recruiting women to CS studies. This premise is in accordance with empirical studies. It was found that women in western cultures perceive their career choice as a vehicle for personal fulfillment and hence prefer that their career be consistent with their self-interest (Pinson *et al.*, 2020; Thebaud and Charles, 2018). Among these interests are the orientation towards interpersonal relations (Thebaund and Charles, 2018), preferences for a career in biology and health sciences (Sikora and Pokropek, 2012), and being mission driven with the desire to contribute to a positive change in the world (Startup Genome, 2018).

The premise is also in accordance with the vast empirical evidence that women are deterred from studying CS because they perceive it as masculine, money- rather than people-oriented, and difficult to combine family and career. Additionally, women lack confidence in their own ability to succeed in the field, and there is a lack of women in CS to serve as role models (Beyer, 2014; Carter, 2006; Dee *et al.*, 2009; Pinson *et al.*, 2020).

Nonetheless, we found no empirical work on what attracts women to study multidisciplinary programs that involve CS, such as bioinformatics. In this study, we aim to address this need. Specifically, we examine the reasons women enrolled and studied bioinformatics as well as their career choices later (if available) in order to determine whether bioinformatics is a gateway for women into CS studies and CS-related careers.

2. Literature Review

2.1. *Women's (Under) Representation in CS Programs*

In many western countries, women are underrepresented in CS programs. For example, in the US, female students make up less than 20% of all undergraduate CS students (Computer Science, 2022; NCSES, 2019; Lehman *et al.*, 2017; U.S. Bureau of Labor Statistics, 2022). The picture is similar in Anglo-Saxon, Scandinavian, and German-speaking (ASG) countries (HESA, 2022; Michell *et al.*, 2017; Women in STEM Statistics, 2021; see also the data of the National Center for Science and Engineering Statistics (NCSES), 2019). According to the U.S. Bureau of Labor Statistics (2022), women in most western countries have remained underrepresented in CS jobs and studies for the past three decades, despite many efforts to recruit women into the field.

2.2. *Factors Underlying Women's Decision (not) to Study CS*

There is vast empirical work on factors that deter women from CS. Most of the studies were conducted in western countries, where women are underrepresented in the field.

2.2.1. *Prior Experience*

For female students, prior experience is a crucial factor for choosing CS (Beyer, 2014; Carter, 2006; Margolis and Fisher, 2002; Pinson *et al.*, 2020).

2.2.2. *A Masculine Image and Negative Stereotypes of CS*

Beyer *et al.* (2003) found that students perceive CS as a masculine domain (similar results were reported by others, for example, Falkner *et al.*, 2015; Leman *et al.*, 2017; Pinson *et al.*, 2020; Singh *et al.*, 2007; Tracy, 1997). In addition, computer scientists are viewed as single-minded, lacking outside interests, and deficient in interpersonal skills. In fact, they are commonly viewed as nerds, geeks, or hackers.

2.2.3. *A Lack of Interpersonal Interaction*

According to Carter (2006), women are interested in fields that are more people-oriented. The image of a CS-related job as people-less, sitting in front of a computer all day, is what deters women from studying CS (see also Beyer, 2014; Thebaud and Charles, 2018; Wilson, 2002).

2.2.4. *Female CS Teachers as Role Models*

Female students who had female CS teachers in high school were more likely to major in CS than those who did not (Beyer and Haller, 2006). Asgari *et al.* (2012) believe that these teachers serve as role models for the female students.

2.2.5. *The Combination of Career and Family*

Women see CS as a domain that makes it difficult to combine family and career, and therefore does not fit a common desire to have a ‘balanced’ life with multiple goals (Carter, 2006; Dee *et al.*, 2009; Eccles *et al.*, 1999).

2.2.6. *Computing with Purpose*

Early studies present a gender-divide perception of men and women to programming, defining the interest of women as “computing with purpose” and of men as “dreaming in code” (Margolis and Fisher, 2002). This insight aligns with women’s interests in fields that integrate values, like helping people, solving universal problems, as well as connected to issues that are more practical (Beck *et al.*, 2007; Carter, 2006; Margolis and Fisher, 2002; Tartaro and Cottingham, 2014).

2.3. *Factors Underlying Women’s Decision to Study CS in Developing Countries and in Minority Groups*

However, there are certain countries, often developing countries (e.g., Malaysia (Lagesen, 2008) and Mauritius (Adams *et al.*, 2003), where comparable numbers of females and males study CS. There are also cases of minority groups in developed societies (e.g., Israeli, Haredi women (Genut and Ben-David Kolikant, 2019)) where there is a similar number of women to men, or more, in CS programs. These studies demonstrate that women are capable of studying CS successfully and highlight the importance of cultural factors.

Adams *et al.* (2003) ascribe the large extent of women representation in CS programs and work market to the macro context of the education system in Mauritius. Specifically, Mauritian female and male students are educated separately at the secondary level. This permits Mauritian women to discover their academic strengths and weaknesses in an environment that is separate from (but equal to) that of Mauritian men. As a result, computing is not perceived as a male domain in Mauritian culture. Negative stereotypes (e.g., CS is for geeks) seem to be nonexistent in Mauritius; instead, computing is seen as fresh, new, modern, and challenging (all of which are positive things).

Both Adams *et al.* (2003) and Lagesen (2008) found that for many of these women in Mauritius and Malesia, CS studies are a means to fulfil their goals of getting a well-paid job as well as a new and interesting opportunity to become skilled and valued.

Noteworthy, the choice to study CS suits the life of women of minority groups within the macro context of their societies. For example, the Israeli Haredi women (Genut and Ben-David Kolikant, 2019), have a unique lifestyle, in which men devote much of their time to religious studies, and women are expected to help support the family and, in many cases, to be the main breadwinner of the family. CS is a good choice for these women because it opens the door for well-paid jobs, and the contents studied do not conflict with their faith. In fact, often female students in minority groups, as well as in developing countries, are "pushed" by their parents to study CS (Adams *et al.*, 2003; Lagesen, 2008; Genut and Ben-David Kolikant, 2019).

2.4. *Approaches to Increasing Women's Representation CS Academic Programs in Western Cultures*

Frieze, Hazzan, Blum and Dias (2006) claim that underrepresentation of women in CS can be addressed by changing environmental conditions and generating cultures of computing that suit women's preferences. Here we review several successful approaches.

2.4.1. *Re-thinking Admission Criteria*

Carnegie Mellon's CS department changed their admission criteria. The new criteria de-emphasize prior programming experience and instead place more emphasis on students' breadth of interests and leadership promise. These new criteria enabled and in fact brought about a more diverse student body than before. Subsequently, the student body became more balanced in terms of gender (Blum *et al.*, 2007; Frieze *et al.*, 2011; Frieze and Quesenberry, 2019; Margolis and Fisher, 2002).

2.4.2. *Increasing the Interaction and Teamwork Among the Students*

One example is the incorporation of agile methods into teaching. Originally, the agile approach was developed to help software development teams achieve their goals faster, breaking the task up into several phases, and involving constant collaboration with team members. It supports communication and information sharing. Findings showed that the agile development environment encourages and stimulates women's equal participation in the agile teams (Blum *et al.*, 2007; Hazzan and Dubinsky, 2006).

Another example is Stanford University and Harvey Maude College, which have adopted a new approach to teaching the CS introductory courses. The courses focus on problem solving, assimilating creativity in performing tasks, and encourage teamwork, thereby reducing competitiveness among students and increasing women's self-efficacy (Globes, 2020).

2.4.3. *Increasing the Number of Women Among Faculty*

Stanford University and Harvey Maude College, USA, have created role models for students from among their increasing number of women faculty members. The number of female students studying computers has increased significantly in these institutes (ibid).

2.5. *Interdisciplinary Fields with CS*

Another approach to expand women representation in CS programs is by offering programs that integrate CS with additional fields, such as biology, psychology, graphic design, and linguistics. Empirical evidence suggests that this approach is effective in attracting women to CS (Ben-Tovim and Kost, 2017). The underlying idea is that in such interdisciplinary programs CS learning is contextualized in problems in which women are interested: contextualized in the real world; issues embedded with values, revolving around improving life and helping people (Beck *et al.*, 2007; LeBlanc and Dyer, 2004; Maloney *et al.*, 2010; Startup Genome, 2018; Tartaro and Chosed, 2015; Tartaro and Cottingham, 2014). Using the words of Margolis and Fisher (2002), such an approach addresses women's interest in "*computing with purpose*."

2.6. *Bioinformatics Undergraduate Programs*

In this study we focus on bioinformatics. In recent years mathematics and languages of CS are used in DNA, RNA, and protein sequence data, as well as other biologically relevant information generated by biologists and stored in databases. Bioinformatics algorithms and computer software are also used in comparing genes or gene products by matching nucleotides or related sequences (Maloney *et al.*, 2010). In addition, theoretical and computational approaches are part of modern drug discovery, using technologies in molecular modeling and chemo-informatics (Prieto-Martínez *et al.*, 2019).

This field of research defines a new interdisciplinary field: bioinformatics, which requires a synthesis of principles from biology and CS, as well as mathematics and chemistry. The rapid rise of bioinformatics as a new field has challenged many colleges and universities to keep up to date with their curriculum.

Accordingly, the number of institutes offering academic programs in bioinformatics has increased. There are some models of incorporating bioinformatics studies into undergraduate CS curricula (Leblanc and Dyer, 2004; Maloney *et al.*, 2010):

- Infusion of bioinformatics content into existing courses.
- Teaming up of biology and CS teachers; for example, by joint, mutually dependent lab exercises or interdisciplinary final projects.
- Team-teaching of bioinformatics involving instructions from multiple departments.

An additional model of bioinformatics integration in academic studies –

- A separate bioinformatics major program, which belong to the more rigorous undergraduates' programs, because of the amount and extent of the biology, chemistry, mathematics, and CS studies needed to specialize in bioinformatics (Leblanc and Dyer, 2004).

Another motive in incorporating biological issues into CS is to attract women to CS studies, as we now turn to explore.

2.7. *Is Bioinformatics a Means to Increase Women Representation in CS Studies?*

Bioinformatics is believed to attract women into CS studies (Beck *et al.*, 2007; Carter, 2006; Lehman *et al.*, 2017; Maloney *et al.*, 2010; Wilson, 2002). Specifically, life science issues, like genome, drug design, protein structure, might serve as the aim for "*computing with purpose*" (Margolis and Fisher, 2002).

Stanford University, the University of Illinois at Urbana-Champaign, the Hebrew University in Israel, and other institutes, succeeded in balancing the number of women in new programs that integrate computing with biology (Globs, 2020).

In fact, many institutes explicitly declare that they offer bioinformatics programs or courses in order to attract women to CS. For example, Truman State University offers an interdisciplinary undergraduate research project in bioinformatics, jointly mentored by faculty in CS and biology departments, as providing for both biology and CS students (Beck *et al.*, 2007). They explicitly declare that the project is "intended to be particularly attractive to women students" (ibid, p.358).

3. Research Questions

As demonstrated above, the literature of programs and courses in bioinformatics include evidence that women's enrolment in these programs is high. Nonetheless, we found no empirical work investigating students' motivation to enroll in bioinformatics programs, their experience of the program, and the ways and extent it has shaped their career. Such empirical work is useful in examining the hypotheses that bioinformatics is indeed a way to expand women representation in CS and a gateway to satisfactory and high-status careers.

Accordingly, our research questions were as follows:

1. What are the factors underlying women's decision to enroll into bioinformatics programs?
2. To what extent, and in what ways, are these students different from those who choose CS?
3. What career opportunities do student anticipate and, in fact, pursue?

4. Methods

4.1. *The Context of the Study: The Jerusalem College of Technology*

Our study was conducted in the Jerusalem College of Technology (JCT). The bioinformatics undergraduate curriculum includes (a) a significant component of the CS undergraduate curriculum, including a track of courses on updated topics in data science and artificial intelligence; (b) life science courses, with emphasis on genetics and molecular biology; and (c) courses on integrated issues of biology and CS, math, and chemistry, e.g., advanced biostatistics, computational biology, and computational chemistry.

4.2. *Process*

We employed a Mixed Methods methodological approach. In stage 1, a comprehensive questionnaire was administered to all female students studying CS in the college, among them those enrolled to the bioinformatics program. In stage 2, after we noticed significant differences between bioinformatics students and other CS students in terms of factors underlying their decision to enrol in their academic programs, we conducted interviews with bioinformatics female students. The interviews enabled us to explore the factors underlying their decision to enroll in bioinformatics studies, the extent to which the studies met their expectations, and their future plans. Finally, in stage 3, we conducted an open-ended questionnaire that was administered to all students and graduates of the bioinformatics program, in order to triangulate and further explore insights obtained through the interviews. Specifically, the open-ended questionnaire enabled us to further examine whether the bioinformatics program succeeds in expanding and diversifying the typecast of the students attending the CS courses (Q1, Q2, Q3), as well as whether it serves as a springboard to a prestigious career (Q4, Q5). Hence our sequence of data collection is both explanatory and exploratory (Shorten and Smith, 2017). Specifically, we used interviews to explain the difference in factors found in the analysis of the questionnaire, but also to explore the unique factors underlying these women's decision to study bioinformatics. The open-ended questionnaire that followed, enabled us to further explore these factors.

4.3. *Participants*

Our research participants were CS female students in JCT during the school years 2018–2019 and 2020–2021. The questionnaire of stage 1 was administered to all 853 female students enrolled in the CS program at JCT towards the end of 2018–2019. A total of 449 students answered the questionnaire (53% of the entire CS female population that year), among them 59 bioinformatics students (57% of the entire bioinformatics students that year).

Fourteen bioinformatics students were interviewed as part of stage 2, conducted in the years 2020–2021. Of them, 7 were in the last year of the program, 4 in the second year, and 3 in the first semester of the program. Finally, the open-ended questionnaire of stage 3 was administered to all the bioinformatics female students (total of 102) and graduates. We received 58 responses: 21 first-year students, 12 second, and 13 third-year students, and 12 graduates.

4.4. *Research Tools*

4.4.1. *Questionnaire*

The questionnaire originally consisted of 71 items, each of which with a 5-point Likert rating scale (‘not at all’ to ‘very much’, or ‘strongly disagree’ to ‘strongly agree’). Using items analysis, 48 items remained, as presented in Table 1). Through these items we examined factors that motivate women to enroll in CS programs (including the bioinformatics program). Elsewhere we have reported the results of the CS majors (Genut and Ben-David Kolikant, 2019). Here, we focus on the significant difference we found between the bioinformatics students and CS students.

4.4.2. *Interviews*

We interviewed 14 female bioinformatics students. We asked them about factors that motivated them to enroll in their studies, the extent to which the program met their expectations, their perceptions of the CS component of the program, and their professional future plans. The protocols of the interviews were transcribed and analyzed thematically (Graneheim, and Lundman, 2004; Patton, 1987).

4.4.3. *Open-ended Questionnaire*

The open questionnaire included the following questions:

Q1: What attracted you to study bioinformatics?
Q2: Which alternative fields of studies did you examine?
Q3: Did the studies meet your expectations? (Not for first year students)
Q4: What are your future plans? (Not for graduates)
Q5: What have you been doing since graduating? (Graduates only)

These questions enabled us to triangulate and extend our insights obtained in stage 2, which, in turn, was based on insights obtained in stage 1. The following examples demonstrate the necessity of all three stages. The questionnaire (stage 1) enabled us to reveal that the bioinformatics students have lower affinity to CS than the CS students. This insight implies that the bioinformatics program expands women representation in CS courses. The insights obtained from the interviews (stage 2) brought us to formulate Q2 in the open-ended questionnaire (stage 3) on the alternative fields of studies students had examined before they decided to enroll in the program. After hearing the interviewees' future plans (stage 2), Q4 and Q5 were formulated in order to examine whether, and to what extent, such a program actually serves as a springboard to a prestigious career.

4.5. *Reliability and Validity*

4.5.1. *The Questionnaire*

We used Item Analysis, in which items were correlated with the items that belonged to the same factor. Correlational values provided evidence indicating that there is enough commonality to justify 7 factors that are significant to the research questions: status; influence by family/role model/others; self-efficacy; lucrative pay; career & family; gender variable; affinity & good image. The reliability of the scale was measured by Cronbach α values within each category (presented in Table 1). The obtained Cronbach's α shows good internal consistency.

Table 1
Factors, Items & Cronbach's α

Category		Number of items	Cronbach's α
Status	It leads to high social status	9	0.855
	It requires continuous intellectual activity		
	It enables social advancement		
	It is a challenging profession		
	It contributes to society		
	It provides prestige and a good reputation		
	It enriches knowledge		
	It enables one to implement initiatives		
	Computer jobs are considered respectable		
Influence by family/role model/others	My parents pressured me to study CS	4	0.614
	I decided to study CS because I had somebody that was a role model for me		
	My family encouraged me to study CS		
	I wanted to be like some programmers in my family		

Continued on next page

Table 1 – continued from previous page

Category		Number of items	Cron-bach's α
Self-efficacy	I am interested in the field	10	0.841
	I am very good in mathematics, which helps a lot in CS studying		
	I like the field of CS very much		
	It enables me to use my abilities to the fullest		
	I have no problem with sitting in front of a computer all day		
	Though the studies are very difficult, they are very interesting		
	Though CS is difficult, it is amazing		
	Though CS is difficult there are terrific courses!		
	I enjoy studying CS for its own sake		
	It is very satisfying to succeed after working so hard		
Lucrative pay	CS enables a good financial foundation	4	0.782
	The financial reward was very significant as a reason in my decision to study CS		
	CS studies increase job opportunities		
	In many jobs it is difficult to combine work with family, but CS at least provides a high-paid salary		
Career & family	It enables free time for leisure with the family	5	0.959
	I plan a big family and CS enables a well-paid job		
	The studies prepare one for a job which is convenient for mothers		
	Family life is my top goal, nevertheless I'll succeed in combining it with work		
	I plan not to invest too much in my work in order not to harm family life		
Gender variable	Women are usually creative hence CS is fitting for them	11	0.737
	Women have no problems with mathematical thinking		
	Women have the ability to solve computer technical problems		
	There are many women who succeed in CS		
	CS is fitting for women because the field requires accuracy		
	Women might choose to study CS if they are encouraged: 'you can do it!'		
	Women who are programmers are realistic and logical thinkers		
	I know women who succeed in combining family life with a high-tech job		
	Each job can be combined with family life if you stick to the appropriate limits		
	Actually high-tech jobs are more difficult but still it's possible for women		
	The world is developing towards more usage of computers, and there is a place for both women and men		
Affinity & good image	Usually, a computer science undergraduate student is good at math	5	0.576
	Usually, a computer science undergraduate student is intelligent		
	I studied CS in high school and found that it suits me		
	I studied CS in the past and I was interested in further computer studying		
	I am enthusiastic about succeeding in solving computing problems		

4.5.2. *Interviews*

We chose 14 female bioinformatics students from different stages of their BSc studies, aiming to capture a variety of viewpoints (Corbin and Straus, 1990). In order to achieve consistency of the analysis of the interviews, each of us analyzed the transcripts separately. Then we compared the analyses, discussed, and resolved the disagreements.

4.5.3. *The Open-ended Questionnaire*

Fifty-eight women answered the open-ended questionnaire. We classified the answers to each question into categories and summarized the distribution of typical answers, as shown in Table 4. In order to achieve consistency of classification, we discussed and resolved the disputes.

5. Findings

5.1. *The Questionnaire*

As mentioned above, we identified seven factors underlying women's decision to enroll into CS studies. We conducted variance analysis (Repeated Measures ANOVA). As shown in the first entry of Table 2 ($F(6, 2682) = 450.063$, $MSE = 75.010$, $p < .001$, partial $eta^2 = .282$), we found that there is a significant statistical difference in the powers of the various factors. Namely, the participants attributed different levels of importance to the various factors.

As presented in the second entry, the interaction between the factors and the group is statistically significant (Factors ✻ Group ($F(6, 2682) = 17.415$, $MSE = 2.902$, $p < .001$, partial $eta^2 = .015$)). This means that there is a statistically significant difference between the group of bioinformatics students and that of CS students in terms of the importance ascribed to the various factors.

In order to identify the factors in which there were statistically significant differences between the two groups, we conducted an independent t-test. Table 3 presents the scores of each factor in each group, as well as the results of the independent t-test.

Fig. 1 illustrates the different ranking of the factors by each group in terms of their importance (according to Table 3). Both groups ranked the factors in the same order, except for the *affinity & good image* factor (i.e., interest in CS and enthusiasm by the field) which was rated statistically significant higher by the CS group. In fact, this factor denotes the *largest* difference between the groups.

Table 2

Within Subjects Effects

	Sum of Squares	df	Mean Square	F	p	η^2_p
Factors	450.063	6	75.010	175.626	< .001	0.282
Factors ✻ Group	17.415	6	2.902	6.796	< .001	0.015
Residual	1145.493	2682	0.427			

Note. Type III Sum of Squares

Table 3
Factors' scores according to CS/bioinformatics

FACTOR	CS		bioinformatics		t	df	p	Cohen's d
	M	SD	M	SD				
Self-efficacy	3.898	0.629	3.602	0.634	-3.369	447.000	< .001	-0.471
Gender variable	3.879	0.537	3.789	0.789	-1.235	447.000	0.218	-0.172
Lucrative pay	3.838	0.79	3.462	0.789	-3.414	447.000	< .001	-0.477
Affinity & good image	3.375	0.758	2.817	0.564	-5.429	447.000	< .001	-0.758
Career & family	3.056	0.685	3.129	0.708	0.759	447.000	0.448	0.106
Status	3.000	0.804	2.971	0.646	-0.260	447.000	0.795	-0.036
Influence of family/ role model / others	2.329	0.819	1.86	0.632	-4.214	447.000	< .001	-0.589

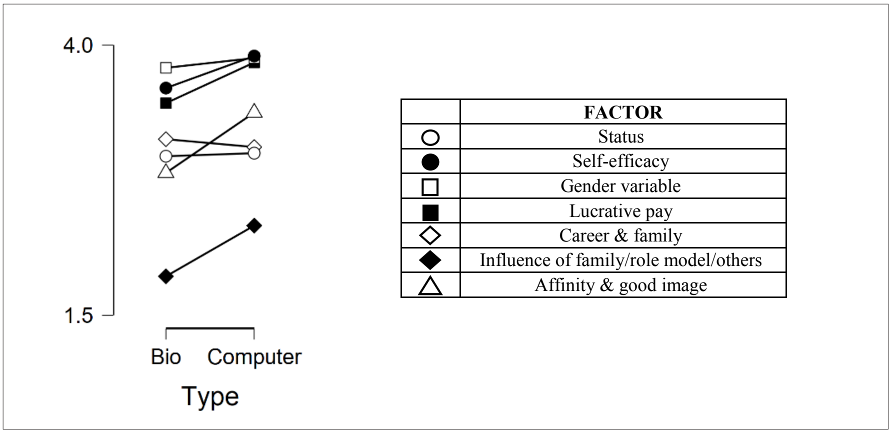

Fig. 1. The rate of the factors according to CS/bioinformatics.

The factors *gender variable* (i.e., the suitability for women), *self-efficacy* (i.e., expectancies of success) and *lucrative pay* were rated high by the two groups. However, the CS group ranked both, the factor *self-efficacy* and *lucrative pay,* statistically significantly higher than the bioinformatics students ($p < 0.001$). No statistically significant difference was found between the groups in respect to the *gender variable* factor.

Career & family factor (i.e., the dilemma of combining career with family life) and the *status* factor were rated lower by both groups with no statically significant difference. Finally, the factor *influence of family/role model/others* was rated lowest by both groups yet was ranked statistically significantly higher by the CS group than by the bioinformatics group ($p < 0.001$).

Namely, the bioinformatics program attracts women with different preferences than those of women who chose to study CS. Specifically, the bioinformatics female students have less affinity to CS, their self-efficacy in CS was lower, they were less motivated by the financial factor, and their family was less influential in their choice than the CS students.

5.2. *Interviews*

5.2.1. *Appreciation of the "Combination"*

When asked what attracted them to study bioinformatics, *all* 14 interviewees mentioned in their answers that the *combination of life sciences with CS* was a main attraction to the program. This main theme was related to three subthemes.

5.2.2. *The Affinity to Life Sciences*

Some of them had studied CS before*: "I knew about the field, that it is biology and computers, two areas that I very, very, very, very much both loved and wanted."* Others were not familiar with the field. Furthermore, students openly admitted they did not really know what bioinformatics is, in particular, how it relates to CS. Yet, they were attracted because they liked biology*: "and I loved biology very much, so I thought Okay, bioinformatics sounds great, I did not really know what [it is], I thought it was an implementation of biological issues on computer. Post facto, I love programming."*

When asked whether they would have studied CS if the choice of bioinformatics studies had been unavailable, the answers varied. Four students would have opted for CS, albeit less happily, as demonstrated in the following two quotes: "*It's a very difficult question… surely [I would have chosen] CS"* and "*I would have been a little disappointed that I had to give up biology, because I loved high school biology, but I guess I would have gone to CS."*

For another four students, CS alone was not an option. Of them, some had never studied CS before: "*I never studied computers, I didn't know what it is, and it seemed a bit risky to study something of which I had no idea, and that would be my future career*." Other had studied CS: "*No, no, there was no way. I was familiar with the field of computers, and I didn't want computers alone, but yes, biology and computers sounded interesting*."

The remaining six interviewees described themselves at the time of choosing the program as perplexed and undetermined, and explained that bioinformatics sounded as a plausible option because they perceived its multidisciplinary nature as enabling wide job opportunities and at the same time an opportunity to study and/or make a living from biology: "*I searched for something with biology, but not "wet" biology, I don't think I wanted high-tech, it attracted me that there is an option to work in biology in high-tech. [I was interested] in the combination".*

5.2.3. *Career with Purpose*

In line with the literature (Beck *et al.*, 2007; Carter, 2006; Margolis and Fisher, 2002) the combination was attractive because of the added value of helping people as demonstrated in the following two examples: "*I wanted to study software, with something else with added value. I wanted something that helps people ... helps the world",* and "*I like to program, but only if it is meaningful, the programming. biologically".* One woman even believed that women programmers are different from male programmers in their interests: "*I can understand why there are more women in bioinformatics. High-tech is more exciting to men because of the money. They are less interested in contributing to the world of research.*"

The advantages of the "combination" of CS and biology were also mentioned when we asked the (seven) interviewees, who were in their last year of the program, if their studies met their expectations. Specifically, this theme was evident in the response of four students, together with the theme of helping the world: *"The combination really excited me… specifically, because it serves humanity at its highest level,"* and *"I just loved the combination of biology and [CS]. Also, the fact that it does something significant, compared to a programmer who works and knows that what he does is not for a value purpose but just out of a motive for money."*

5.2.4. *Learning to Like CS*

Except for one student, the encounter with CS was intriguing to the students: "*Although I have not studied computers before, I really do not know what has changed in me, maybe the understanding of what I am doing, maybe the success, but actually today it [programming] is really exciting.*" Yet, as one of them explained, CS alone was still not an option. CS was a means to put into practice the content they valued: "*I learned to love programming, but only if it makes sense ... to provide solution for human needs; that's why I am interested in research.*" The exceptional interviewee expressed disappointment from the program because of the extensive CS studies it requires: "*I was disappointed. I did not know how much computers take up in bioinformatics and how much I do not connect with this field.*"

5.2.5. *A Springboard to a Prestigious Career*

When asked about future plans, five out of the 14 told that they are interested in an academic research career when graduating. They explained that this type of career will enable them to combine *career and family* in contrast to work in the high-tech industry: "Y*es, (I chose bioinformatics) because of the possibility of continuing in research. In fact, academia is more convenient for the family compared to high-tech, which is more demanding." "It seems very hard to be a mom and work in high-tech. If [work in] research allows less hours to work, it will be perfect.!"*

5.3. *The Open-ended Questionnaire*

Table 4 presents the distribution of the responses to each question. In Q1 we inquired what attracted the student to the bioinformatics program. In line with the literature and the interviews, many students were attracted because of their interest in the life-sciences (40%) or the combination between life-science and CS (22%). Apparently, a substantial factor is the future directions this program is perceived as opening (12%).

Q2 indicates that 28% of the students have considered CS as an alternative and another 7% considered engineering professions. However, in line with the literature, 62%

reported on considering "people-oriented" disciplines, such as social science, life sciences and medicine.

According to the responses to Q3, the program met the expectations of the majority of the students. However, it did not meet the expectations of 29% of the students. The two most common reasons were that they did not like one of the two disciplines and that they had found it to be too difficult.

Table 4

The distribution (%) of answers of the open questionnaire

		first year N=21	second year N=12	third year N=13	gradu-ates N=12	total group
	IDN	%	%	%	%	%
						N = 58
Q1 What attracted you to study bioinformatics?	Interest in medicine-biology-chemistry (life science) fields	35	40	40	48	40
	A program that combines several domains	18	28	29	22	22
	Interest in Computer Science-programing fields	28	16	12	15	18
	An opportunity to become skilled in practical, prestigious, requested and well-paid fields in the industry (and also the opportunity of getting high-tech jobs), offers many new future opportunities	11	12	19	15	12
	Other factors	8	4	11	11	8
		100	**100**	**100**	**100**	**100**
Q2 Which alternative fields of studies did you examine?	Life-sciences, health professions, medicine	35	50	38	45	41
	Computer science / computing engineering	30	33	18	30	28
	Social sciences & humanities	28	6	20	25	21
	Electro-optical / biomedical / chemical / food / industrial engineering	7	0	24	10	7
	There was no other alternative	0	11	0	0	3
		100	**100**	**100**	**100**	**100**
						N=37
Q3 Did the studies meet your expectations?	Yes/beyond expectations		61	42	50	51
	Doesn't meet the expectations		7	7		4
	To some extent		8	10	11	9
	Much more difficult than I expected		8	11	16	11
	I realized that one of the areas is not so interesting (only one of them)		16	6	6	9
	Don't know (including, there were no special expectations)		8	6	6	7
	Disappointment from lack of jobs in the field			6	11	5
	Reason not specified			12		4
			100	**100**	**100**	**100**

Continued on next page

Table 4 – continued from previous page

	IDN	first year N=21 %	second year N=12 %	third year N=13 %	graduates N=12 %	total group %
						N=46
Q4 What are your future plans?	Graduate studies / medical studies	12	60	39		40
	Find a job (high-tech)	19	17	39		24
	To be involved in research / in bioinformatics-medicine	43	17			24
	Still do not know / unsure	10	6	22		12
		100	**100**	**100**		**100**
						N=12
Q5 What have you been doing since graduating?	Graduate studies / PhD studies / medical studies				42	42
	Programmer / software engineer / software developer / data science				34	34
	Teaching certificate				8	8
	Work in a research lab in a hospital				8	8
	Housewife, raising my children				8	8
					100	**100**

Finally, the students' responses to Q4 on their plans for their professional future indicate that a high percentage of respondents are interested in pursuing academic studies and research (71% first year students; 78% second year students; 39% third year students). Moreover, looking at the responses to Q5, where we asked graduates about their current stage in their professional lives, these plans are realistic: 42% of the graduates who responded enrolled in advanced academic studies (M.Sc and PhD programs) and 34% work as computer programmers.

6. Discussion and Conclusions

The goal of this study was to examine in what way, if at all, bioinformatics programs expand and diversify women representation in (a) CS studies; and (b) CS-related career paths.

6.1. *Bioinformatics: A Means to Expand and Diversify Women Representation in CS Programs?*

The comparison between women who study the CS program and those in the bioinformatics program, in terms of the factors underlying their decisions to enroll in their programs, revealed a statistically significant difference. Bioinformatics students had significantly less affinity to CS and had less self-efficacy in CS than the CS students. They were also significantly less influenced in their choice by their family and less motivated by financial considerations. This finding implies that the bioinformatics program attracts women who differ from those attracted to CS.

The analysis of the open questionnaire revealed that many women were attracted to the bioinformatics program because of their affinity to biology (or the combination of biology with CS). Less than a third would have considered CS as an alternative in case they could not study bioinformatics. Rather, the majority would have chosen to study life sciences, medicine, humanities, and social sciences.

Finally, most of the students reported that the program met their expectations or even better surpassed their expectations. The interviews reveal that some had never been exposed to CS studies before, nor did they know what bioinformatics is, but chose it because of their affinity to biology. Yet they learned to love CS. In line with the literature, however, some women mentioned that it is the computing with purpose, the values, that they like (Beck *et al.*, 2007; Carter, 2006; Margolis and Fisher, 2002; Tartaro and Cottingham, 2014).

We can conclude that the bioinformatics program succeeds in attracting women, who would not have enrolled in CS initially, thus expanding and diversifying the typecast of the students attending the CS courses.

6.2. *Bioinformatics: A Springboard to a Lucrative Career?*

When asked about their plans for the future, most students reported that they wanted to carry on with research mostly in medicine and bioinformatics. About two thirds of them planned graduate studies in these fields and the remaining third planned a research career in these fields without mentioning graduate studies. In line with the assertion in the literature on women's interest in a 'mission-driven' occupation (Beck *et al.*, 2007; LeBlanc and Dyer, 2004; Maloney *et al.*, 2010; Tartaro and Chosed, 2015; Tartaro and Cottingham, 2014), several women mentioned during the interviews that career in research suits their desire to work with purpose. They mentioned that such a career path would also allow them to combine career with family. Indeed, the number of academic papers published by women in computational biology lies in between the number of papers published by women in CS and in biology (Bonham and Stefan, 2017). About a quarter of the students planned to pursue a career in high tech.

Based on the responses to the open questionnaire of 12 women who successfully graduated it seems that that the future plans of the students are realistic: Three of them work in high-tech (or bio-tech) companies and 5 of them are enrolled in graduate studies in medicine and bioinformatics. Hence, we can conclude that bioinformatics indeed opens diverse opportunities to distinguished careers, in bioinformatics-related jobs, as well as in academic research.

Obviously, our study has limitations. We examined one program in one institute, albeit with a diversified student population. Future research is needed in order to enable more generalization of our findings. Yet, this study sends an encouraging message that diversifying and expanding CS classes is feasible. Moreover, these studies indeed serve as a springboard to satisfactory careers.

6.3. *Bioinformatics: Which Women Does it (not) Suit?*

We do not claim that bioinformatics is the sole solution to expanding women representation in CS classes and diversifying the typecast of CS students. On the contrary. For example, biology might hinder certain groups in the society as it conflicts with their faith (Stahi-Hitin and Yarden, 2022). In our own previous studies (Genut and Ben-David Kolikant, 2019; Kolikant and Genut, 2021) we found that for Hasidic and Ultraorthodox Jewish women, where women are often the main providers, CS is considered a discipline "clean" of conflicts, and a means to provide for their family and combine family and work. For these women, for example, bioinformatics is not an option.

Rather these programs address the needs of certain women, who have affinity or positive image of biology as a discipline that leads to meaningful careers in terms of helping people, or improving the world. Bioinformatics programs offer these women, using their words, the "combination" of computing with purpose. Synthesizing our results with the literature it seems that bioinformatics programs suit Western women, for whom a career is seen as a tool for personal fulfillment and aligns with their self-interest. For these women, factors such as influence in their career choice by their family as well as financial considerations do not play a central role (Pinson *et al.*, 2020).

This study reinforces the claim that in order to attract underrepresented groups to CS (or any other discipline), we should understand which factors deter these groups from CS and which attract them, and we should address these factors.

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