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# UNDERGRADUATE HAREDI STUDENTS STUDYING COMPUTER SCIENCE: IS THEIR PRIOR EDUCATION MERELY A BARRIER?

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## ABSTRACT

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| Aim/Purpose | Our research goal was to examine whether the prior, Talmud-based education of ultraorthodox Jewish men is merely a barrier to their academic studies or whether it can be recruited to leverage academic learning. |
| Background | This work is in line with the growing interest in extending the diversity of students studying in higher-education institutes and studying computer science (CS) in particular. |
| Methodology | We employed a mixed-methods approach. We compared the scores in CS courses of two groups of students who started their studies in the same college in 2015: 58 ultraorthodox men and 139 men with a conventional background of Israeli K-12 schooling. We also traced the solution processes of ultraorthodox men in tasks involving Logic, in which their group scored significantly better than the other group. |
| Contribution | The main contribution of this work lies in challenging the idea that the knowledge of unique cultures is merely a barrier and in illustrating the importance of further mapping such knowledge. |
| Findings | The ultraorthodox group's grades in the courses never fell below the grades of the other group for the duration of the five semesters. Due to their intensive Talmud studies (which embeds Logic), we hypothesized they would have leverage in subjects relating to Logic; however this hypothesis was refuted. Nevertheless, we found that the ultraorthodox stu- |

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| | dents tended to recruit conceptual knowledge rather than merely recalling a procedure to solve the task, as novices often do. |
| Recommendations for Practitioners | We concluded that these students' unique knowledge should not be viewed merely as a barrier. Rather, it can and should be considered in terms of what and how it can anchor and leverage learning; this could facilitate the education of this unique population. |
| Impact on Society | This conclusion has an important implication, given the growing interest in diversifying higher education and CS in particular, to include representatives of groups in society that come from different, unique cultures. |
| Future Research | Students' unique previous knowledge can and should be mapped, not only to foresee weaknesses that are an outcome of "fragile knowledge" , but also in terms of possible strengths, knowledge, values, and practices that can be used to anchor and expand the new knowledge. |
| Keywords | computer science, diversity, prior education, Talmud, Logic |

## INTRODUCTION

There is a growing interest in extending the diversity of students studying in higher-education institutes in general, and studying computer science (CS) in particular. Postsecondary education confers numerous benefits both to the individual and to society, including higher incomes and lower rates of unemployment and government dependency. Studying CS as a major domain can be a springboard for successfully entering the labor market and, in turn, for increasing social mobility. Graduates can pursue a career in CS and in other relevant areas. However, the lack of diversity in computing has existed for decades (McGill, Decker, & Settle, 2015) at all levels.

There are many barriers to college access and success. One such barrier is affordability. Another potential barrier is a lack of preparation for higher education. In this work we focus on adults who did not undergo core studies (e.g., math, sciences, and English) education during their childhood and youth, and who would like to study CS in order to get a high-paying job that would enable them to provide for themselves and their family. Can they succeed in higher education studies?

More specifically, this work concerns the integration of Israeli ultraorthodox Jewish men into CS academic studies, in particular the role that their unique, previous education plays. The ultraorthodox Jewish community (*Haredi*) has radical and stringent religious demands. These men lack a conventional high-school education and, hence, they underwent little if any core studies (math, sciences, information-communication technology, English, and so forth). Their education is based mostly on studying the Talmud, which we explain later.

As in the case of other minorities, the unique education and upbringing of ultraorthodox Jewish men is often perceived as a *barrier*, preventing them from studying CS as well as the domains of science, technology, engineering, and Mathematics (STEM), which in turn, prevents them from getting high-wage jobs. However, little is known about this issue empirically. In this work we examine this assumption and present our results. Employing a mixed-methods methodological approach, we compared the scores of Israeli ultraorthodox men who studied CS with a group of men with conventional K-12 schooling, and who had studied the same program. We also traced the solution processes of ultraorthodox men in tasks involving Logic, in which their group scored significantly better than the other group.

## LITERATURE REVIEW

As mentioned above, the ultraorthodox Jewish community (*Haredi*) has radical and stringent religious demands. This group is divided into many subgroups that differ from one another in their specific ideologies and lifestyles. In 2014 the ultraorthodox Jews comprised about 11% of the Israeli population.

Many of the Haredi men do not participate in the Israeli labor force. Instead, they devote most of their time to studying in a *yeshiva* (Talmudic academia, discussed later). Specifically, according to the Israeli Central Bureau of Statistics (2015), 56% of Haredi men were employed (in comparison with 89% of the general population of men in Israel, ages 25-64). As a result of the low employment rate and their low personal income, most ultraorthodox households are below the poverty line. In fact, 52% of the Haredi population is below the poverty line in comparison with 19% of the general population. This tendency has been stable since 2006. The percentage of ultraorthodox children in poverty is very high (67%) and their per capita income is 47% lower than that of the general population.

In recent years the government of Israel has invested substantial efforts in integrating Haredi people, both men and women, into the labor force, in ways that would improve their economic situation, yet allow them to maintain their unique life style (Gal, 2015). One such endeavor is to enable and facilitate this population to pursue academic education, which in turn would enhance their chances to work in high-paying jobs. However, this is not trivial when it concerns ultraorthodox men, given their unique prior education, which we will now explain.

Ultraorthodox Jewish men lack conventional, formal education including science, mathematics, technology, and English. In fact, in 2013 only 2% of Haredi boys earned matriculation certificates (in contrast to 17% of Haredi girls) (Malach, Choshen, & Cahaner, 2016).

As Davidman and Greil (2007) put it, "Haredi (including Hasidic) Jews, like other highly encapsulated groups, provide environments that are insulated from secular life in a variety of ways" (p. 205), including their unique education system. The K-12 education of Haredi men is based almost exclusively on sacred texts, mostly the books of the Talmud (sometimes they study for 10 hours a day). Talmudic texts commonly take the form of a written transcript of an ever lively, usually agonistic, and occasionally vituperative oral discussion. The most common contemporary framework for the Talmudic study process within the study hall is the *Havruta*—(lit. company, friendship, from *Haver*: friend)—paired study. The students of the *yeshiva* have pages of the Talmud before them and they collaboratively engage in debating the meaning of any given section while intellectually juggling a host of other interpretations given for the same section, whether recorded on a given page or not (Blum-Kulka, Blondheim, & Hacohen, 2002).

These studies differ from academic studies not only due to the different contents studied, but also in the learning values advocated. Academic studies are goal oriented (tests, degrees, and so forth), whereas the ultraorthodox religious values encourage engagement with the sacred texts as a worthwhile activity on its own. Torah li-shma (Torah is the first part of the Hebrew bible), namely, study as an end in itself, is a central ideal in this lifestyle (Blum-Kulka et al., 2002), which might be expressed in the development of certain habits of mind, such as critical reading, paying attention to nuances, and being explorative and inquisitive (Dembo, Levin, & Siegler, 1997).

However, there are also overlaps between Talmudic studies and other fields. A prominent overlap is Logic. The Talmud is a body of arguments and discussions about all aspects of human life: social, legal, and religious. This canonical text was completed over 1500 years ago, and its argumentation and debates contain many logical principles and examples (Abraham, Gabbay, & Schild, 2011b). Applying appropriate strategies is at the core of Talmudic learning. General and possibly conflicting tasks are often involved in Talmudic learning, in which the learner must apply Logic and make decisions in an unknown new situation (Abraham, Gabbay, & Schild, 2009, 2011a, 2011b; Abraham, Gabbay, Schild, Hazut, & Maruvka, 2011).

Abraham et al. (2009, 2011a, 2011b) show how forms of basic rules in Talmudic Logic can be transformed into general frameworks that are very much relevant to today's research in Logic, artificial intelligence, law, and argumentation. They use mathematical formulations of problems in the Talmud, creating loops, matrices, and equations.

However, significant differences exist between Talmudic and mathematical Logic. One is that the Talmudic texts do not include any logical or mathematical symbols and formulations (Dembo et al., 1997). Another prominent difference is the ways in which a statement is determined as "true". In mathematics and in many scientific disciplines, two opposing propositions cannot be simultaneously declared as "true". The "truth" of a statement is based on its coherence (or agreement) with all narratives that have been endorsed up to that point. Talmudic justification, on the other hand, involves reasoning between several, often equally plausible alternatives. Consequently, one's Talmudic interpretation must be supported by evidence, but it does not necessarily refute other interpretations (Segal, 2011), as mathematical or scientific counter-examples do.

Computer education has many advantages with respect to this population. It has potential to offer jobs with higher wages. The field of computing does not conflict with faith and ideology. One can work from home and use a 'kosher Internet program', namely have access to the Internet, which is restricted according to different Haredi requirements (Campbell & Golan, 2011). In a survey conducted in 2008 by the Ministry of Economy, 49% of ultraorthodox men were interested in academic education, and of these, 23% were interested in computer education of some sort (Malachi, Cohen, & Kaufman, 2008).

There is vast work on how to get students from the underrepresented groups to enroll in CS programs and how to make it more approachable to those students from underrepresented groups who have enrolled in CS classes. The former is challenging due to the image of CS as an asocial, tedious and boring profession, for geeks (Porter, Guzdial, McDowell, & Somon, 2013).

The latter is challenging as well. There is a high dropout rate (Bennedsen, & Caspersen, 2007; Kinnunen & Malmi, 2006), especially from those groups in CS. Varma (2006) and others (e.g., Goode, 2008; Guzdial & Forte, 2005) contend that CS courses can and should be made more minority-friendly and focus on the importance of building on students' capital and their prior, unique knowledge. Often, attempts to build on students' capital have focused on increasing their motivation and their sense of the relevance of CS, as well as making sense of concepts through examples from their own cultural world.

These challenges, although important on their own, are less relevant to our work, since building on students' capital means not only building on the unique parts of this capital, but also on students' acquaintance with the contents, norms, and practices of conventional schooling, which is not the case when considering ultraorthodox men, as we explained.

The unique prior education of ultraorthodox men, though rich in knowledge of Talmud, is often perceived as a barrier, "a lack of general studies, matriculation certificates, and professional qualifications" (Malach et al., 2016, p.8). Their intensive studies are viewed as adding low if any value to their academic studies (Cohen, 2005; Gal, 2015). However, we found two empirical works, both in mathematics, which suggest that their unique ultraorthodox upbringing may leverage academic learning. Dembo et al. (1997) compared the performances of two groups of Israeli male students, those attending mainstream, secular schools, and those in ultraorthodox systems (age groups of 12-14, 16-18) in solving geometric misconception problems. Interestingly, the ultraorthodox 12 to 14-year-olds performed better than their secular peers, although they had not previously received instruction in geometry. Among the 16 to 18-year-olds, the secular students did somewhat better, but this advantage was limited to those secular students who had studied the most advanced mathematics curriculum. Ultraorthodox and secular students both benefited, to equal degrees, from training aimed at improving their understanding of geometry. Dembo et al. (1997) ascribe the advantages of the ultraorthodox lifestyle to the characteristics of their education, especially the values of in-depth understanding and the tendency to read critically.

The work by Ehrenfeld (2016) further reinforces the hypothesis that a Talmudic background can leverage academic studies. Ehrenfeld (2016) examined the discourse of ultraorthodox men who had studied mathematics in a preparatory course and found that students set goals and utilized practices of exploration and discussion with peers, which enabled them to delve into problems, gain a conceptual understanding, and solve them (see also Ehrenfeld, Heyd-Metzuyanim, & Onn, 2015). However, we found no other empirical work about Haredi students learning of STEM education in higher education or at any other level.

Is the unique Haredi background merely a hindrance to their CS academic studies or could this unique background positively affect their learning? CS is a discipline that relies both on mathematics (especially Logic) and on engineering. The ultraorthodox men lack a body of knowledge, gained throughout a formal school education as well as experiencing life in a modern world, which could bring about difficulties when studying CS. On the other hand, these students bring to class their positive, unique learning habits from the yeshiva. Specifically, their pursuit for truth might transfer to an in-depth exploration for a conceptual understanding, as reported by Dembo et al. (1997) and Ehrenfeld (2016). Additionally, their Talmudic learning involves an intensive use of Logic, since it involves logical arguments. Hence, they might possess a general conceptual framework of logic that they could apply to a new context.

# METHODOLOGY

## *RESEARCH OBJECTIVES AND HYPOTHESES*

We considered three objectives. The first objective was to examine whether the prior education of ultraorthodox male students is merely a barrier to their CS studies. To this end, we compared the achievements of ultraorthodox and non-ultraorthodox men who had studied the same CS program. If indeed their prior education was merely a barrier, it would be expressed in lower performance and higher dropout rates. We will refer to this hypothesis as H1. The opposite hypothesis was that the performance of the ultraorthodox would be no less than that of the second group due to certain strengths, which we also sought to explore and describe.

To this end, we posed the second and the third objectives. Our second objective was to examine the assumption that the ultraorthodox students' acquaintance with Logic during their Talmudic studies would facilitate their learning of Logic in the context of CS studies. Therefore, we compared the performances of ultraorthodox and non-ultraorthodox men in the course on digital systems, the first course in which they were introduced to concepts in Logic in their academic studies. Again, two contrasting hypotheses were examined. One, that the acquaintance of the ultraorthodox group with Logic would be transferred to the new context, CS, which would be manifested in a higher performance in the course than that of the second group, who had not engaged in Talmud studies to this extent. We will refer to this hypothesis as H2. On the other hand, the Logic studied in Talmud studies is different (e.g., the notion of truth) and the context of CS greatly differs from that of Talmud studies. Therefore, the ultraorthodox students might not find this knowledge useful, or may use it inadequately; hence, they would not perform better than the other group.

Finally, we considered an exploratory objective of monitoring ultraorthodox men as they solved tasks in topics in which they had performed better than the other group, in order to gain insights into their academic strengths.

## *RESEARCH METHOD*

We employed a mixed-methods methodological approach and, more specifically, a quantitatively driven mixed-methods approach. In such an approach, the research study is, at its core, a quantitative study. The qualitative method is added to supplement and improve the quantitative study by providing an added value or more complex answers to research questions (Creswell, 2013).

In our case, the first two objectives were addressed quantitatively. In order to address the first objective, we compared the grades of the ultraorthodox male students with other male students in compulsory courses in the CS program over 5 consecutive semesters. The second objective was addressed by comparing the two groups' performance in a test consisting of tasks in Digital Logic. The third objective was addressed qualitatively. We used talk-aloud protocols in order to explore the strengths of the ultraorthodox students as they solved tasks in Digital Logic.

## *PARTICIPANTS*

The participants were undergraduate students at a college of technology in Jerusalem, Israel. Most of the students at this college are religious Jews, although from different social groups. Women also study at this college but at a separate campus.

We focused on two groups of men. One group consisted of ultraorthodox men whose prior education lacked almost any general high-school education, and, instead, they had studied religious subjects for at least 4 years, sometimes studying more than 10 hours a day, specifically Talmudic studies. Before starting their academic studies, they are obligated to participate in a one-year preparatory program that includes a basic high-school education. We will refer to this group of students as the Talmudic group (TG). Their ages ranged from 23 to 28.

We compared the performances of TG in CS courses with a second group, male students who underwent a conventional Israeli high-school education. We will refer to this group as the conventional group (CG). We chose to refer only to the male students in order to eliminate issues related to gender differences. Their ages ranged from 19 to 25.

Most of the CG members were religious. Their high-school education included religious studies, which also included Talmudic studies, but they were not as broad and deep as in the TG. These men had earned a full matriculation certificate with an advanced program in Mathematics. In Israel, this sector (Dati Leumi, or national religious Jews) has better academic achievements in comparison with other sectors in Israel. For example, Feniger, Mcdossi, and Ayalon (2015) found that this sector performed better in reading comprehension tests conducted by the Programme for International Student Assessment (PISA) than did the secular Jews.

Our participants started their academic studies in 2015. Specifically, in 2015, TG consisted of 58 students and CG consisted of 139 students.

## *RESEARCH TOOLS*

### Grades

We compared the achievements of students in the TG and CG in compulsory courses in the CS program over 5 consecutive semesters. These courses involve mathematics, computer programming, and theoretical computation.

### Dropout rates

We calculated the dropout rates of the participants in CG and TG.

### The test

In order to assess students' understanding in four main topics of digital Logic (State and sequential circuits, Number representations, MSI components, and Boolean Logic), we used questions from the Digital Logic Concept Inventory (DLCI) (Herman, 2011; Herman & Handzik, 2010; Herman, Kaczmarcczk, Loui, & Zilles, 2008, 2012; Herman, Loui & Zilles, 2009, 2010, 2014; Herman, Zilles & Loui, 2011). A concept inventory (CI) is a standardized assessment tool designed to measure students' understanding of the core concepts of a topic (Goldman et al., 2010), i.e., the extent to which it matches the accepted conceptual framework of a discipline.

We used the latest version of the Digital Logic Concept Inventory (DLCI), DLCI β1. This version was administered at six institutions in the United States and provided a representative sampling of 688 students from across the country.

Specifically, we selected six items from the DLCI β1(Herman, 2011) and included them as part of the final examination of the course Digital Systems. The entire examination included 16 items. We will refer to the six items as *the test*. The test is presented in the Appendix. Table 1 describes the concepts examined. For each concept, we listed the items used for its examination: their original DLCI β1 numbering and their numbering in the test)

**Table 1. The items in the test**

| Concept | DLCI β1 | Test |
|---|---|---|
| • State and sequential circuits, especially the<br>▪ Relationship between states and flip-flops | 6,17 | 1,4 |
| • Number representations<br>▪ Two's complement representation, overflow | 14 | 2 |
| ▪ Number bases | 16 | 3 |
| • Functionality of MSI components<br>▪ Decoders and multiplexers | 24 | 5 |
| • Boolean logic<br>▪ Underspecified Boolean functions<br>▪ Boolean operators (the Don't Cares) | 21 | 6 |

We compared the performances of the different groups, namely, the TG and CG. First, we examined whether the difference in the groups' performances for the entire test was statistically significant (assessed by the average scores and calculating the p-value), and, additionally, we compared the performance of each item (also, assessed by the average scores and by calculating the p-values).

### Talk-Aloud Protocols

Shortly after the test, we interviewed four students from TG. We selected those students who had earned grades of 40-80% on the test. Each student was asked to answer the same four open-ended questions, while expressing his thoughts. The questions spanned the topic of number representation. We chose this topic because TG performed significantly better on this topic than CG did. In order to trace students' thought process, we needed questions that they did not see before; therefore, we used questions previously used in the early stages of constructing the DLCI. In the analysis of the transcriptions, we traced students' solution processes and reasoning, the strategies used, the knowledge expressed (correct and incorrect), verification methods, and so forth, in order to gain insights on how they dealt with the tasks. To this end, we relied on relevant codes constructed by the administrators of DLCI (Herman, 2011; Herman, Kaczmarcczk, Loui, & Zilles, 2008; Herman, Zilles, & Loui, 2011).

## *Data Collection Process*

The test was conducted in the first semester of the school year of 2015-2016, as part of the examination in the course on digital systems, the first course in which students were introduced to concepts in Logic in their CS studies. This course is a 3.5 credit course, given in the first semester of the first year. In total, 326 students took the final examination of the course (including women). Of these, 58 students belonged to TG and 139 to CG.

The comparison revealed an advantage for TG in comparison with CG, but in only two items. This led us to pose the third objective and develop the talk-aloud protocol, which were conducted shortly after the test.

Finally, in 2017, the grades of those students who began their studies in 2015 (and were still enrolled in college) were compared. In each course we compared two groups of course participants—ultraorthodox students (i.e., TG) and non-ultraorthodox students (i.e., CG). We noted that there was a certain dropout rate in both groups and, therefore, in order to examine the role it played, we calculated the dropout rates as well.

## *RELIABILITY AND VALIDITY*

### The Test

We based our method of analyzing the test's reliability and validity on the methods used in DLCI for the same purposes (Herman, 2011; Herman & Handzik, 2010, Herman, Loui, & Zilles, 2010; Herman, Zilles & Loui, 2014).

We calculated Cronbach's α for the full examination (16 items) and for the test (6 items). Both were calculated for the entire population that participated in the examination, 326 students (comprising TG, CG, and women). Cronbach's α for the full examination (16 items) is 0.68. Cronbach's α for the test is 0.416.

Apparently, Cronbach's α for the test is a poor value (a Cronbach's α of 0.60 or above is generally considered acceptable for typical classroom assessments (Jorion, James, Schroeder, & DiBello, 2013)). However, it resembles Cronbach's α values for DLCI β1 for a population of 377 students (0.54) as well as the values of Cronbach's α values conducted for each subtopic of DLCI β1, which included 5-7 items each (0.45-0.57).

Construct validity evaluates whether the items actually test the concepts that they were intended to test (Streveler et al., 2011). The construct validity of DLCI was established by having the Delphi experts rate the quality of each item and suggest improvements. The distractors were constructed and verified (to ensure that students select a particular distractor for the reasons predicted) using personal interviews with students (Herman, 2011). In our work we relied solely on these measures of validity.

### The Talk-Aloud Protocols

In order to achieve reliability, we worked as follows. First, each of us analyzed two transcripts separately. Then, we compared and discussed the analyses and resolved any disagreements. In the consecutive iteration, we analyzed all four transcripts separately, and discussed and resolved the few disagreements that we had.

# RESULTS

## *TG'S ACHIEVEMENTS*

Table 2 presents the comparison between the achievements of students in TG and CG who took the obligatory CS courses for five consecutive semesters. The courses are classified into three categories: mathematics, programming, and theoretical computing.

The results show a slight advantage for TG. In three courses TG performed better than CG, by a statistically significant difference: Infinitesimal Calculus 1 ($t(136) = 2.339, p = 0.021$), Infinitesimal Calculus 2( $t(132) = 2.035, p = 0.044$), and Differential Equations( $t(100) = 1.985, p = 0.049$). In all other courses there was no statistically significant difference. Except for one course, TG's course average was slightly better than that of CG.

**Table 2. Scores of the TG and CG**

| COURSE | SEMESTER | TG | | | CG | | | STATISTICS | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | N | MEAN | STDV | N | MEAN | STDV | t | df | p |
| **Mathematics** | | | | | | | | | | |
| Infinitesimal Calculus 1 | 1 | 46 | 86 | 10 | 92 | 79 | 19 | 2.339 | 136 | 0.021* |
| Infinitesimal Calculus 2 | 2 | 46 | 86 | 12 | 88 | 80 | 18 | 2.035 | 132 | 0.044* |
| Linear Algebra 1 | 1 | 45 | 79 | 10 | 93 | 76 | 16 | 1.152 | 136 | 0.251 |
| Linear Algebra 2 | 2 | 44 | 80 | 11 | 84 | 78 | 17 | 0.706 | 126 | 0.481 |
| Differential Equations[2] | 2-4 | 34 | 88 | 11 | 68 | 81 | 19 | 1.985 | 100 | 0.049* |
| **Computer programming** | | | | | | | | | | |
| Introduction to Computer Programming | 1 | 41 | 80 | 11 | 91 | 77 | 17 | 1.035 | 130 | 0.303 |
| Programming in C++ | 2 | 36 | 83 | 10 | 81 | 76 | 23 | 1.751 | 115 | 0.082 |
| Programming in windows | 3 | 29 | 87 | 9 | 56 | 87 | 8 | 0 | 83 | 1 |
| Digital Systems | 1 | 48 | 73 | 12 | 91 | 71 | 28 | 0.472 | 137 | 0.638 |
| Digital Logic | 3 | 30 | 80 | 13 | 60 | 78 | 16 | 0.593 | 88 | 0.555 |
| **Theoretical computing** | | | | | | | | | | |
| Data Structures and Program Design 1 | 2 | 30 | 76 | 9 | 60 | 77 | 16 | -0.318 | 88 | 0.751 |
| Data Structures and Program Design 2 | 3 | 30 | 80 | 13 | 60 | 78 | 16 | 0.593 | 88 | 0.555 |
| Automata & Formal Languages | 4 | 15 | 76 | 13 | 34 | 68 | 23 | 1.257 | 47 | 0.215 |
| Computer Algorithms | 5 | 19 | 80 | 11 | 23 | 79 | 12 | 0.279 | 40 | 0.782 |

* denotes a statistically significant difference between the groups (p-value <0.05).

## *STUDENTS' DROPOUT RATES*

It is noteworthy that the number of course participants decreased from the first to the fifth semester (Table 2). We therefore examined the dropout rates of the two groups and found that they were similar. Specifically, of TG that started their studies in 2015, 20% dropped out in the first year and 16% in the second year, in comparison with 16% and 19% of CG, respectively. Hence, hypothesis H1 was refuted.

## *The Test*

Hypothesis H2---that TG will do better in the Digital logic tasks than CG did--- was refuted as well. On the test, CG performed slightly better (Mean = 3.64, SD = 1.49) than TG (Mean = 3.44, SD = 1.67), yet the difference between the groups was not statistically significant $t(195) = 0.790$, $p = 0.430$.

The results of the comparison between TG and CG in each item of the test are presented in Table 3. TG performed better than CG regarding the topic of number representations (items 2 and 3). These differences are statistically significant ($p<0.05$, Table 3). In the remaining four tasks, there were no statistically significant difference between TG and CG.

**Table 3. Comparison of performance on the test items for TG and CG**

| ITEM | TG | | CG | | STATISTICS | |
|---|---|---|---|---|---|---|
| | N | CORRECT RESPONSES(%) | N | CORRECT RESPONSES(%) | Z | P |
| 1 | 58 | 48 | 139 | 53 | -0.640 | 0.522 |
| 2 | 58 | 73 | 139 | 57 | 2.227 | 0.026 |
| 3 | 58 | 78 | 139 | 64 | 2.060 | 0.039 |
| 4 | 58 | 53 | 139 | 61 | -1.032 | 0.303 |
| 5 | 58 | 58 | 139 | 58 | 0 | 1 |
| 6 | 58 | 51 | 139 | 57 | -0.770 | 0.441 |

## *Talk-Aloud Protocols*

For each question, we present the goal of the question, as formulated by Herman (2011) and Herman et al. (2011). We describe the approaches employed by the students in our study.

### Question 1 - Comparing numbers

*Question 1:* Which number is greater?

I. $(11010)_2$ or $(32)_{10}$?

II. $(2B)_{16}$ or $(31)_{10}$?

Herman et al. (2011) found that students prefer to solve this question (and similar ones) by converting the numbers to decimal base. Moreover, they reported that with hexadecimal base, students prefer first to convert it to binary base and often then to decimal base. According to Herman et al. (2011), the over-reliance on converting to binary first, though not a misconception, is indicative of novice behavior, since it concerns *using procedural knowledge* not necessarily derived by *conceptual understanding*.

In our study, only one student applied the “conversion” procedure in question 1.I. The remaining three students did not convert the numbers at all. Rather, they used an approach derived from conceptual understanding. Specifically, they indicated that $(11010)_2$ is less than $(32)_{10}$ by noting that $(11010)_2$ does not extend into 32’s place in binary base.

The same conceptual understanding was evident in one student’s responses to question 1.II; the student explained that $(2B)_{16}$ is more than $(31)_{10}$ by noting that the weight of digit 2 in the number $(2B)_{16}$, by itself is 32, which is greater than 31. He correctly calculated only the value of the significant digit (digit 2 of the number $(2B)_{16}$) according to its place (32), and since 32 already is larger than 31, he did not need to complete the conversion.

### Question 2 - Subtraction in binary base

> *Question 2:* Subtract the following numbers, which are in binary base:
>
> 1110011 – 0011110=

In order to solve this equation, students had to perform the borrowing operation. Most of them (three out of four) solved this question incorrectly. When subtracting the third digit from the right, students had to borrow $(100)_2$. Instead, they borrowed $(1)_2$. A similar mistake was reported by Herman (2011) and Herman et al. (2011). Similarly to Herman's reports, these students recalled (incorrectly) procedural knowledge. Apparently, they did not employ any checking procedure, which would have informed them they were wrong.

### Question 3 - Two's complement representation

> *Question 3:* The number 0100101 is represented in 7-bit two's complement.
>
> I. What is the number?
>
> II. What is the advantage of two's complement representation?

In response to part I of this question, only one student represented the number as $(1011011)_2$, a common mistake (Herman, 2011; Herman et al., 2011), whereas the others responded correctly, $(37)_{10}$. According to Herman et al. (2011), this mistake is due to students' confusion between "two's complement representation" and "two's complement operation"; thus, they interpreted the number 0100101 in 7-bit two's complement as $(1011011)_2$ or $(91)_{10}$.

In response to part II, three reasons were provided by the four TG students. Similarly to the students in Herman's (2011) work, all four of them mentioned that (a) two's complement representation has only one representation for zero, and that (b) it can represent more numbers than any other representation. However, there is a third reason: (c) it simplifies the hardware implementation of subtraction, as well as the addition of positive and negative numbers. The last reason was rarely mentioned by Herman's students, although it is the primary advantage of using the two's complement representations. This could imply a lack of understanding the relationship between the topic of number representation and the structure of the computer, and a misunderstanding of its significance (Herman, 2011). In this study, all of the students mentioned the third reason, which reinforces our argument that they employed a conceptual understanding, and took into account the relationship between hardware and number representation.

### Question 4 - Overflow

> *Question 4:*
>
> I. Give an example of overflow.
>
> II. Which of the following 2's complement additions result in overflow?
>
> 1. 0110+ 1010 2. 0110+0101

This question was designed to reveal students' understanding of the implications of the fixed length of a register in a computer, as well as their understanding of one of its implications, the concept of overflow. Understanding the implications of the fixed lengths of registers in a computer is perceived as one of the most counter-intuitive concepts related to the interpretation of numbers (Herman, 2011). It is therefore common that students have difficulties when they need to deal with operations that involve numbers of a fixed length. Furthermore, they often struggle to understand the concept of overflow. Since a conceptual understanding of overflow requires an underlying conceptual understanding of the structure of a register in a computer, many students fail to solve overflow problems correctly. In their solution attempts, they often rely on operational/situational definitions of overflow, such as "overflow happens when the addition of two positive numbers results in a negative number" (Herman et al., 2011, p. 84). Namely, they recall, rather than exhibit a conceptual understanding.

In our study, all the students answered this question correctly. All of them correctly demonstrated a case of overflow, entailing a correct explanation that overflow occurs because of the fixed length of the registers. The tendency to utilize conceptual knowledge was prominent in one student's approach. He converted the numbers to decimal representations, 5 and 6, and concluded that the addition, 11, is larger than the largest number that can be represented (7); hence, the addition will result in an overflow.

The results of the talk-loud protocols revealed that although students had fragile knowledge, they tended to employ a conceptual understanding rather than solely recalling procedures to technically solve the problems.

## DISCUSSION

Our main research goal was to examine whether the prior knowledge of Haredi students is merely a barrier to CS academic studies, as is often viewed in public discourse. To this end, we compared the achievements of TG and CG in compulsory courses in CS for five consecutive semesters. Interestingly, TG consistently scored no lower and even scored higher than did CG. The dropout rates in both groups were similar. We thus refuted hypothesis H1, that students' previous education (and life experience) is merely a barrier. Apparently, the ultraorthodox male students have the ability to study CS successfully.

This ability is impressive, given that their knowledge of mathematics, English, and sciences—deemed important for CS— relies almost exclusively on the one-year preparatory course. Was their unique education a source of strength? Hypothesis H2, that TG will do better in the Digital logic tasks than CG did, was refuted. Logic is inherent in Talmudic studies (Abraham et al., 2009a, 2011b); hence, it was reasonable to assume that students' acquaintance with Logic would be transferred to their CS studies, especially in courses that involve direct instruction of Logic concepts, which was our second research objective. However, the results were mixed. Namely, TG did not perform better than CG in all the test questions. Specifically, they performed significantly better in items concerning number representations, whereas in other items there were no significant differences. We thus concluded that although Logic is inherent in Talmudic studies, its transfer to a CS context is not straightforward.

Rather, these results pinpoint the need to further understand the links between the unique knowledge of these students and the new knowledge with which they deal. The in-depth investigation of students' solutions of tasks concerning number representation, our third research objective, revealed that, as in the case of typical novices, their conceptual knowledge relevant to the topic was fragile. However, often they pursued conceptual understanding, in comparison with the typical novice-like tendency to solve a problem by merely recalling a procedure, without necessarily understanding the underlying concepts and their interrelation (Herman, 2011, Herman et al., 2011). This tendency is in line with the work of Dembo et al. (1997) and Erenfeld (2016), who found that students with a Talmudic background employed learning practices and habits of mind derived from a tendency and commitment to in-depth explorations in order to gain a conceptual understanding. Dembo et al. (1997) and Erenfeld (2016) attributed this tendency to the unique educational experience of the students. For example, Erenfeld (2016), who investigated the learning processes of ultraorthodox men during the preparatory course in mathematics, found that the Talmud learning experience, such as the ideal of getting to the truth (rather than accepting an authoritative voice), was expressed in students' questioning of any possible solution.

One may argue that these students have certain attributes, such as curiosity, resourcefulness, and intelligence, and that is what underlies their tendency to engage in in-depth explorations, as well as their success in this new and alien area. Future work is required to examine and elucidate this possibility. If indeed, this is the case, the difference must be rooted in their previous, unique knowledge, either gained throughout their unique schooling experience or their life experience in the unique culture in which they were raised.

In addition, it can be argued that the one-year preparatory makes the difference. However, if this was the case per se, it would be reasonable to assume that in other high-education institutions those students who participated in the preparatory course would achieve no less or even better than those who underwent conventional k-12 education. This is not the case, usually, for various reasons, such as low esteem, low intrinsic motivation, insufficient academic background, and the intensity of the preparatory program (Gero & Abraham, 2016; Zoabi, 2012). This again, invites an exploration of the unique knowledge and life-experience of this group.

## CONCLUSIONS

The performance of the ultraorthodox group was no less and even slightly better than that of the non-ultraorthodox despite their lack of core studies. We can conclude that these students' unique prior knowledge was not merely a source of their weaknesses—it could also be a source of their strength. This conclusion has an important implication, given the growing interest in diversifying higher education in general, and CS in particular, to include representatives of groups in society that come from different, unique cultures.

Obviously, the present study has several limitations. First, we examined only one group of students who studied in one institution. The findings suggest that groups with a unique previous education could study in higher-education institutes despite their lack of core studies; however, many questions are raised. Are the results dependent on the institute? Is this success unique to the ultraorthodox society, or can we assume that the knowledge deduced from this study can be applied to other groups with a unique education (or perhaps only to groups with certain attributes that the ultraorthodox also have)? Can these groups succeed in other domains or only in CS? A future research study is required to address these questions, by examining the performances of samples of students from the same social group who study in different institutes, students from other groups with a unique education, students who study other domains, and so forth.

Second, the methods used in this work were insufficient to determine the strengths that the students' previous, unique experience and knowledge provided them in their academic studies (e.g., unique characteristics, certain habits of mind, contents, and so forth). However, this work is valuable in highlighting the potential of this unique knowledge and the need to explore it further. Students' unique previous knowledge can and should be mapped, not only to foresee misconceptions, namely, faulty extensions of previous knowledge, and weaknesses that are the result of "fragile knowledge" or the absence of a certain body of knowledge (e.g., Herman's DLCI), but also in terms of possible strengths, knowledge, values, and practices that can be used to anchor and expand the new knowledge.

Mapping would be beneficial, for example, to address questions raised in this study, such as why number representations were better understood than other topics, and what previous knowledge could have enhanced the understanding of the other topics if they were properly introduced.

Much empirical work exists in the CS literature reporting successful attempts to build on students' capital (e.g., Eglash, Bennet, O'donnell, Jennings, & Cintorino, 2006; Guzdial & Tew, 2006). However, we do not aim at increasing students' motivation or their sense of the relevance of the topic studied in their day-to-day life as in the abovementioned studies, but rather, the approach we suggest is concerned with mapping or assessing students' existing knowledge while looking for strengths, i.e., the possible productive and nonproductive extensions of existing knowledge and practices in order to cope with and assimilate the new knowledge studied.

Such a pedagogical approach might be beneficial in terms of reducing the drop-out rates because it might aid the teaching/learning process by allocating more or less time according to the knowledge mapped, thus devoting more time to deal with to fragile or absent pieces of knowledge, and tackling unforeseen misconceptions.

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# APPENDIX

## *THE ITEMS OF THE EXAMINATION*

*Question 1*: (Question 6 of DLCI β1.0 Form A (Herman, 2011, p. 242))

Which statement best defines the word *state* when used to describe a sequential circuit?
1. State is the current value of all flip-flops in the circuit.
2. State is the current value of all inputs in the circuit.
3. State is the current value of all outputs in the circuit.
4. State is the current value of all flip-flops, and inputs and outputs in the circuit.

*Question 2:* (Question 14 of DLCI β1.0 Form A (Herman, 2011, p. 250))
Which of the following 4-bit **two's complement** additions could result in an overflow? Each variable (a, b, c or d) is either 0 or 1 independent of the values of the other variables.
I. 00ab+1101
II. 00cd+0110
1. II only
2. I only
3. I and II
4. None

*Question 3*: (Question 16 of DLCI β1.0 Form A (Herman, 2011, p. 254))
Which statement is true about the two sets of numbers?
1. $(2.7)_{10} > (2.7)_{16}$ and $(1.3)_{10} > (1.3)_{16}$
2. $(2.7)_{10} < (2.7)_{16}$ and $(1.3)_{10} < (1.3)_{16}$
3. $(2.7)_{10} = (2.7)_{16}$ and $(1.3)_{10} = (1.3)_{16}$
4. $(2.7)_{10} > (2.7)_{16}$ and $(1.3)_{10} < (1.3)_{16}$
5. $(2.7)_{10} < (2.7)_{16}$ and $(1.3)_{10} > (1.3)_{16}$

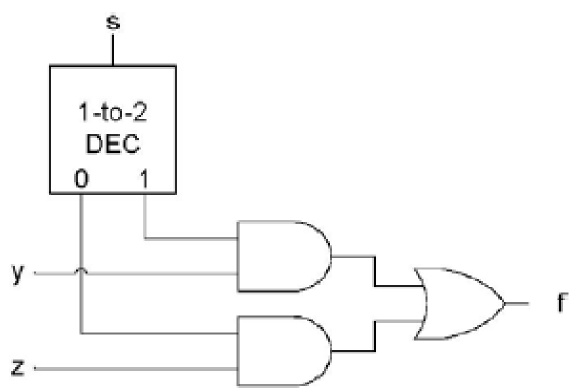
*Question 4*: (Question 17 of DLCI β1.0 Form A (Herman, 2011, p. 254))

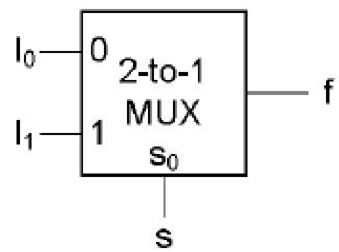
What is the maximum number of distinct states of a sequential circuit that has 0 inputs, 3 flip-flops, and 2 outputs, which can potentially be over time?

1. 8
2. 1
3. 3
4. 0
5. None of the answers.

*Question 5*: (Question 24 of DLCI β1.0 Form A (Herman, 2011, p. 260))

**Question 24.** Below and to the left is a proposed implementation of a 2-to-1 multiplexer (MUX). The proposed circuit is constructed from a 1-to-2 decoder (DEC ) and three additional gates. Which bit assignment should be used to make the two circuits have the same behavior (i.e., both implement the same function f)?




2-to-1 Multiplexer

| s | f |
|---|---|
| 0 | $I_0$ |
| 1 | $I_1$ |

Proposed implementation of a 2-to-1 MUX

1) The proposed circuit does not implement the 2-to-1 MUX.
2) The proposed circuit implements the 2-to-1 MUX only when $\langle y, z\rangle = \langle I_0, I_1\rangle$.
3) The proposed circuit implements the 2-to-1 MUX only when $\langle y, z\rangle = \langle I_1, I_0\rangle$.
4) The proposed circuit implements the 2-to-1 MUX when either $\langle y, z\rangle = \langle I_0, I_1\rangle$ or $\langle y, z\rangle = \langle I_1, I_0\rangle$.

*Question 6:* (Question 21 of DLCI β1.0 Form A (Herman, 2011, p .256))

**Question 21.** A combinational circuit is specified by the truth table below. For three input combinations, the output of the circuit does not matter ("don't-care"). The specification is implemented as a circuit using the following Boolean expression: $f = \bar{a}\bar{c} + b$. What will the circuit output when it receives the input combination <*a*,*b*,*c*> = <1,1,0>?

1) 0
2) 1
3) X (don't care)
4) Unknown

| *a b c* | *output* |
|---|---|
| **0 0 0** | 1 |
| **0 0 1** | 0 |
| **0 1 0** | 1 |
| **0 1 1** | 1 |
| **1 0 0** | 0 |
| **1 0 1** | X (don't-care) |
| **1 1 0** | X (don't-care) |
| **1 1 1** | X (don't-care) |

## Biographies

**Dr. Sara Genut** is currently the Academic Head of the Machon Tal Campus at the Lev Academic Center in Jerusalem. Dr. Geniu overseas multiple departments which include Engineering, Computer Science, Nursing, Accounting, and Business Administration. She has served as an adviser to the Israeli Ministry of Education. She led the effort in adopting reforms in Science and Technology Educational Systems. Her research focuses on Science in Education. Dr. Genut holds a Ph.D. in Science Education from the Hebrew University of Jerusalem, Israel, received in 2001.

**Yifat Ben-David Kolikant** is a Senior lecturer in the School of Education at the Hebrew University of Jerusalem. Dr. Ben-David Kolikant's research focuses on examining the tripartite relationship of students, school learning, and technology in the information era. Mainly, her research revolves around two inter-related questions: (1) How does students' knowledge of subjects outside of school impact on their school learning? And, (2) what pedagogies are suited to the information age and the needs of students and what role does technology play? Dr. Ben-David Kolikant holds a Ph.D. degree in science teaching from the Weizmann Institute of Science, received in 2002.