THE EFFECT OF SECONDARY MATHEMATICS ON FUTURE CHOICE IN STEM PROFESSIONS

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Reducing leakage from STEM to non-STEM professions is important, mainly due to the great demand for quality manpower in STEM fields. This study aims to characterize learners who have the potential to drop out of STEM fields, as well as examining various pathways in which dropout occurs. Using big-data analysis based on 534,590 records retrieved from the CBS in Israel for several points in time over one and a half decades, we identified eight pathways to choosing a profession from secondary school to graduating a bachelor's degree, and characterized learners in each pathway based on educational characteristics. Findings reveal three dominant pathways of which one reflects a leakage from STEM in secondary school to non-STEM in higher education. Further, advanced secondary math is the best indicator of completing a STEM degree.

INTRODUCTION AND THEORETICAL BACKGROUND

Despite the growing demand for experts in STEM fields, many studies show a decline in the choice of STEM professionals throughout lifespan. This trend is referred to as the Leaky Pipeline Metaphor (LPM: NRC, 1986). The LPM describes the phenomenon of practitioners dropping out of various STEM fields throughout lifespan, starting from secondary school when the number of potential practitioners is relatively high, continuing into and graduating from STEM studies in higher education, and eventually working in STEM fields (Witteveen & Attewell, 2020) when the number of practitioners in STEM professions is alarmingly low (OECD, 2019).

Dropouts during higher education studies are not limited to STEM subjects. Yet, the LPM only accounts for dropouts from STEM fields, rather than the movement from non-STEM into STEM fields (Witteveen & Attewell, 2020). In addition, the leaking is not linear, so that students who drop out of STEM studies at some point in lifespan, may return later on to the field (Lykkegaard & Ulriksen, 2019). Therefore, along with efforts to hold the leak among STEM students, it would be worthwhile to make efforts to increase the number of streams from non-STEM fields to STEM fields.

Secondary mathematics have been found to provide a good foundation for later STEM studies, and entry into higher education (Kohen & Nitzan, 2021a; Sadler, Sonnert, Hazari, & Tai, 2014). The PCAST report (2012) indicates that a lack of substantial math skills often prevents students from choosing STEM fields for study, as mathematics is regarded as a fundamental subject for all other sciences (Li, 2013). Also, choosing STEM major in secondary school serves to develop and promote students' aspirations for future studies and careers in STEM fields (Holmes, Gore, Smith, & Lloyd, 2018).

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The present study explores diverse pathways for choosing a profession, by examination the choice of STEM and non-STEM fields as a profession during significant periods in lifespan, starting from secondary school, first year of higher education, and graduating a bachelor's degree. The data for this study that was retrieved from the Central Bureau of Statistics (CBS) in Israel enabled mapping the characteristics of learners in each pathway according to educational variables that had been found to influence profession choices, in particular mathematics and science studies and achievements in these subjects in secondary school.

Theoretical framework – The integrative four-phases model for career choice

The integrative model suggested by Reinhold, Holzberger, and Seidel (2018) is a four-phases model that expresses the operational of goals for choosing a future career according to significant periods in life. The first phase, the wishing phase, allows interests in a diverse career area with little commitment, characterizing students in elementary and junior high school, who are not required to choose any field of specialization in studies. The second phase, the planning phase, represents a growing commitment to a particular career field, based on ability and performance, characterizing students in secondary school who are required to select a major subject for study. The third phase, the action phase represents the actions taken to realize the chosen career, characterizing students in higher education studying for an academic certificate. Finally, the fourth phase, the pursuing phase, represents the attainment and persevering in the chosen career, characterizing the employed in the labour market.

The nature of the data at our disposal, indicating an actual objective choice, did not allow an examination of the wishing phase. In Israel, STEM education is mandatory before secondary school and is studied as a general subject. Therefore, our focus is on the last three phases that reflect actual choices towards a career, namely planning, action, and pursuing.

The phases in this study are defined as follows: The *planning* phase refers to choosing STEM as a major in secondary school, which was found to play a critical role in the likelihood of students to reject, persist or enter STEM fields (Engberg & Wolniak, 2010). The *action* phase is defined by choosing STEM as a major in first year in higher education, which is a critical crossroad towards choosing a career profession (Witteveen & Attewell, 2019). The *pursuing* phase is defined by obtaining a bachelor's degree in a STEM field, which indicates attainment and persevering in the field as a future occupation, as STEM graduates are more likely to work in STEM professions (Kohen & Nitzan, 2021b).

Secondary school mathematics and future STEM choice for study and career

Succeeding in mathematics during secondary school is considered an important factor in developing and promoting student's confidence in their ability to pursue a STEM career and is a good predictor of future STEM academic success and career (Kohen & Nitzan, 2021a; Holmes et al., 2018). A longitudinal study revealed that those who excelled in mathematics in secondary school were twice as likely to be employed in STEM professions than those with low mathematics achievements (Anlezark, Lim, Semo, & Nguyen, 2008). Also, secondary school STEM studies lay the foundation for further STEM studies in higher education (Lichtenberger & George-Jackson, 2013), and an interest in majoring in STEM in secondary school is affected by future employment orientations. Thus, students who wish to pursue a STEM career may start to take an interest in these fields in secondary school, so they can better prepare themselves for these studies in higher education.

AIM AND RESEARCH QUESTIONS

The aim of the present study is to characterize different pathways according to important stages in the lifespan and to examine educational data that identifies the learners in the various pathways. Accordingly, the research questions are:

1. What are the possible pathways to STEM and non-STEM bachelor's degrees, starting from secondary school through higher-education and graduation?
2. What are the characteristics of each pathway and how do they differ based on various educational variables?
3. Over different stages of life, what are the characteristics that best predict STEM choice?

METHODOLOGY

Secondary mathematics and STEM major in Israel. At 10th grade, Israeli students are required to choose a major subject, usually at an advanced level. There is also a division into three levels of mathematics, each with different levels of depth and topics covered. The basic level, that is the minimum required for obtaining a matriculation certificate, requires skills that are mainly applied techniques. The standard level provides a solid foundation of skills and knowledge of mathematics. The advanced level is the highest level, when emphasis is on developing mathematical-scientific thinking, designed to direct students towards STEM studies.

Participants

A base population of 534,590 Israeli secondary school students were sampled for this study. Data was obtained from the CBS in Israel, using systematic sampling that contains all secondary school population who graduated secondary school over one and a half decade, in the years 2001, 2006, 2011, 2015, and 2017.

Observed Variables

The CBS data allows to track student educational choices and achievements from secondary school to graduates and employees. The codebook that guided the analysis was comprised of educational data, including level of secondary mathematics, type of science major, and the level of success in mathematics and science major in secondary school. Based on the matriculation exam in math and science, this study defined success as a dichotomous variable, representing excellence when the score ranges between 91 to 100, or not excellent if it falls below 90.

The definition of the STEM values, which have been validated by experts, are as follows: *STEM subjects in secondary school* include the areas of physics, chemistry, biology, and computer science; *STEM subjects in higher education* refers to the following subjects: mathematics, statistics and computer sciences; physical sciences; biological sciences; agriculture; medicine; or engineering and architecture. The remaining subjects were defined as non-STEM values.

RESULTS

Pathways to STEM or non-STEM degree

In order to identify pathways for STEM and non-STEM bachelor's degrees, we created a three-tiered tree. Based on frequencies analysis, the first tier represents the major subject that was studied in secondary school, namely STEM or non-STEM. The second-tier divides each of the first two branches according to the choice made in first year of higher education. This tier was obtained using a Chi-Square test which combined descriptive distribution of STEM or non-STEM subjects studied in secondary school and first-year in higher education. The third tier builds on the previous two, and represents eight pathways, from secondary school to obtaining a bachelor's degree. For that we ran a split-file based on the type of major studied in secondary school, followed by a Chi-Square test based on the choice made in first year of higher education and the completion of a bachelor's degree. Each pathway was given a number from one to eight, so that a higher number indicates persistence in choosing STEM over the years. The internal ranking between these pathways was performed according to the degree of persistence and selection sequence in STEM throughout the three stages of life examined. For example, learners in pathway #8 were ranked at the highest grade, since they persevered in the STEM professions in all three stages examined and completed a STEM degree. Figure 1 presents visually the three-tiered tree of pathways toward STEM or non-STEM degrees.

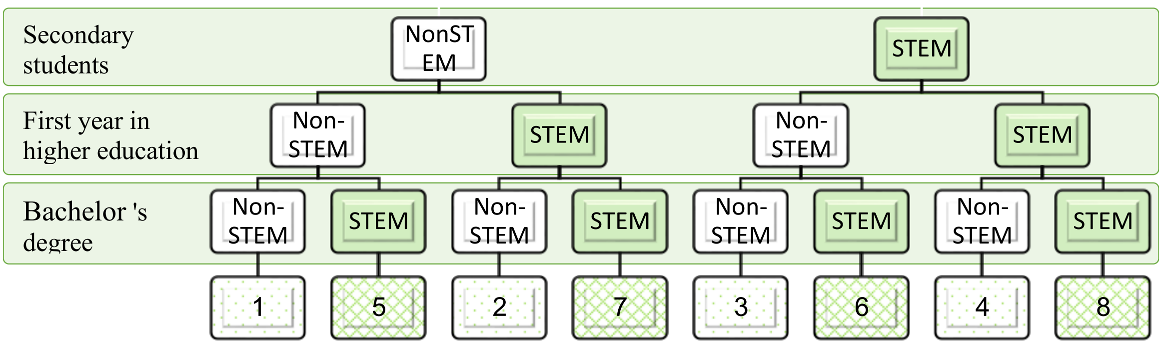

Figure 1: The three-tier tree, representing eight pathways toward STEM or non-STEM profession.

There is a similar distribution of STEM or non-STEM choices in secondary school, with STEM fields being favoured (57.2%). In higher education, almost 43% of those who studied STEM in secondary school choose a STEM field in their first year, as opposed to less than 13% of those who studied non-STEM. The distribution of graduates revealed an ongoing impact of the choices made at school. About 85% of STEM graduates, studied STEM major in secondary school compared to only 15% who studied non-STEM major. When focusing on absolute numbers, the three-tiered tree indicates three dominant pathways. Pathway #1 reflects about 35% (*N*=83,984) of total students, who persist in choosing a non-STEM field from secondary school throughout bachelor's degree graduation. Pathway #8 reflects the 22% persistent students (*N*=53,132) who followed a STEM path from secondary school to bachelor's degree graduation. Finally, there is pathway #3 which reflects about 33% of students (*N*=77,088), who studied STEM in secondary school, but chose a non-STEM track in higher education. As these three pathways reflect most of the students in the study sample who completed a bachelor's degree, at this point we base our findings on these three dominant pathways.

The characteristics of the dominant pathways.

For mapping the characteristics for each of the three dominant pathways, Chi-Square tests were conducted. Additionally, a Kruskal-Wallis analysis of variance was performed for analysing the statistical differences between the different pathways, in relation to each of the educational characteristics.

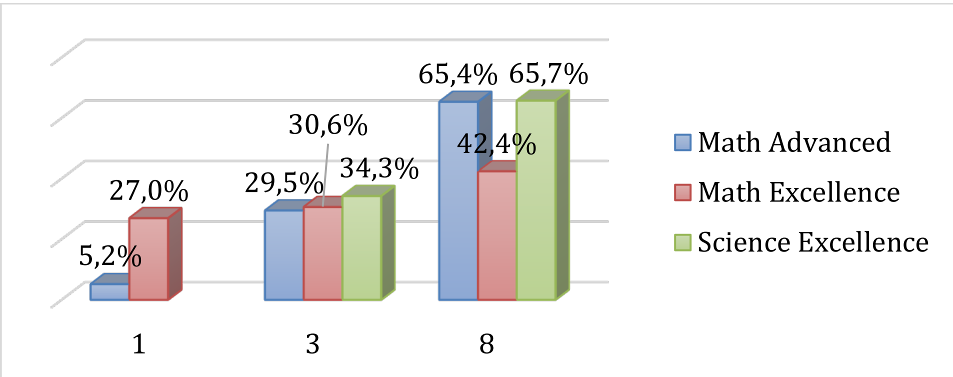

Figure 2: The distribution of the characteristics of the dominant pathways.

Kruskal-Wallis test revealed significant differences between the three dominant pathways in most characteristics. Most students who persist in the STEM path (#8) studied advanced mathematics and excelled in mathematics in secondary school compared to students in the non-STEM path (#1). In path #3, no significant difference was found in the distribution of these variables. It appears that there is another salient feature in path #3 which impacts the transition from STEM studies in secondary school to non-STEM studies in higher education.

Distribution by major field in secondary school. Figure 3 presents the distribution of the types of secondary STEM major for pathways #3 & #8, which are the ones that started in STEM studies in secondary school. Results revealed a statistically significant difference between these pathways in the distribution by all STEM majors. Those who studied physics and computer science, are more likely to follow path #8, whereas those who studied biology and chemistry are more likely to follow path #3.

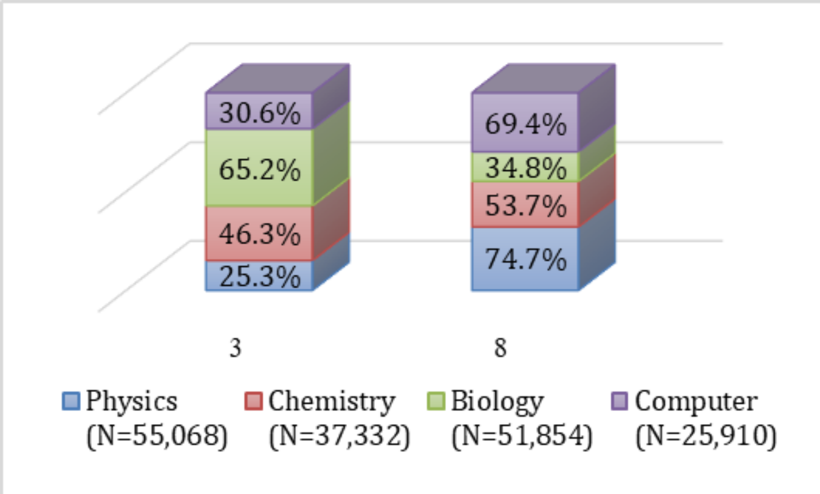

Figure 3: The distribution by STEM major type in secondary school.

Predicting the completion of a STEM bachelor's degree

A logistic regression revealed that all the investigated educational characteristics predict the likelihood of pursuing and completing a STEM undergraduate degree. The most influencing variable is the math level, meaning that students who study advanced mathematics are more likely to graduate STEM as a major in bachelor's degree, compared to students who study non-advanced mathematics in secondary school. Science major success level was found to be the second in predicting completion of a STEM undergraduate degree. As for the types of STEM majors, physics was found to be the best predictor of completing a STEM undergraduate degree, while biology was the least likely (see Table 1).

Characteristic	Predictor	B	Wald χ^2	Odds Ratio
Math level	Advanced compared non-Advanced	.56***	789.44	1.75
Math success	Excellence compared to non- Excellence	.11***	34.20	1.12
Science major success	Excellence compared to non- Excellence	.30***	183.62	1.36
Science major type	Physics	.21***	1867.21	1.24
	Chemistry	.10***	543.45	1.11
	Biology	.06***	153.40	1.06
	Computer science	.15***	965.95	1.16

Table 1: Regression findings for predicting the completion of a bachelor's degree in STEM.

DISCUSSION

Through a big data analysis, this study presents a three-tier tree which recognizes various pathways that lead to a STEM or non-STEM bachelor's degree, of which three were found to be the most dominant, reflecting the largest number of leaners who completed a bachelor's degree. The most significant finding is the recognition of path #3, that is a learner who started STEM in secondary school and moved to non-STEM in higher education. First, and contrary to the assumption underlying Reinhold et al. (2018) integrative model, the transition from the wishing phase to the planning phase is not the critical stage to choosing a specific career, as this study suggests that the critical transition occurs between the planning phase and the action phase. That is, the biggest leak of STEM learners to non-STEM fields occurs in the transition between secondary school to higher education. Further, this study shed some light on the characteristics of learners who persevere in STEM studies and those who drop out of STEM studies immediately after secondary school. We can point to a combination of characteristics in accordance with path #3 that do not encourage continued selection in STEM fields in higher education, for example students who did not study advanced mathematics and did not excel in mathematics and in the science major in secondary school, as well as students who studied biology or chemistry in secondary school. Therefore, and in accordance with the regression analysis, in order to encourage STEM choice in higher education and the completion of a STEM bachelor's degree, we might be focusing on increasing the percentage of students studying physics and computer sciences in secondary school, as well as those who study advanced mathematics. Finally, the identification of diverse pathways and characterization of learners in each path, develops new avenues through which the choice of STEM subjects can be preserved.

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