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International Journal of STEM Education (2022) 9:63
https://doi.org/10.1186/s40594-022-00381-9

International Journal of
STEM Education

RESEARCH

Open Access

Secondary school mathematics and entrance into the STEM professions: a longitudinal study

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Abstract

Background: STEM (Science, Technology, Engineering, and Mathematics) fields are in high demand for qualified personnel worldwide, yet drop-out rates of a career path in STEM occur at various points in lifespan. Based on a big-data analysis of 534,590 records retrieved from the Israeli Central Bureau of Statistics for several points in time over one and a half decades, the study aims to examine the various pathways of which secondary school students take toward STEM-related careers, and to characterize each pathway based on various demographic and educational factors.

Results: The study presents a three-tier tree, which highlights eight pathways leading to STEM or non-STEM bachelor's degrees. An important finding is the recognition of a non-linear pathway, demonstrating the biggest 'leak' from STEM in secondary school to non-STEM in higher education. Further, findings indicate that choosing advanced mathematics, majoring in physics and computer science in secondary school, and excelling in mathematics or science major at secondary school, have a lasting effect on STEM persistence in higher education. Additionally, males and non-minorities populations have the highest likelihood of choosing STEM for future studies.

Conclusions: The study contributes theoretically to broadening the conceptualization of various pathways toward pursuing a STEM career across important choice stages in people's lifespan. Moreover, the study provides insight into the long-term effect of education choices made in secondary school, as well as demographic and educational factors, on future choice for study.

Keywords: Advanced mathematics studies, Big-data analysis, Ethnic minorities gaps, Gender gaps, Model of Career Self-Management, Social Cognitive Career Theory, STEM profession choice

Introduction

Despite the increasing demand for experts in the STEM (Science, Technology, Engineering and Mathematics) fields, many studies show a decline in the choice of STEM as a profession throughout lifespan (Leu, 2017; Miller, 2018). Vast research had been done relating to students' orientations toward STEM professions, focusing on STEM trajectories or pathways (e.g., Cannady et al., 2014; Wang & Degol, 2013). In particular, numerous studies have considered dropouts from STEM fields, as referred to as the Leaky Pipeline Metaphor (LPM) (National Research Council, 1986). LPM describes the phenomenon of students leaving the STEM field throughout lifespan, starting from secondary school when the number of potential students in the STEM fields is relatively high, continuing with STEM studies in higher education, eventually graduating, and ultimately working in STEM fields, in which the number of practitioners in the STEM professions is appallingly low (OECD, 2021; Staus et al., 2019).

Research into the leaky pipeline has explored what influences students' choice of STEM majors, as well as their retention in these fields (e.g., Linnenbrink-Garcia et al., 2018). The drop-out movement, however, is not linear, and students who drop out of STEM studies may later return (Lykkegaard & Ulriksen, 2019). Also, other directions can account for the opposite movement

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as well, i.e., from non-STEM to STEM (Witteveen & Attewell, 2020; Wu & Uttal, 2020). An extensive theoretically sound method is required to understand the various pathways of which high school students take toward STEM-related careers.

Although vast research had been done in this field, most studies have been based on large-scale surveys, either through a retrospective view of bachelor's degrees graduates who recall their experiences in secondary school (e.g., Green & Sanderson, 2018; Sadler, et al., 2012), or through a prospective view of secondary school students who express early career aspirations toward future STEM choice for study and career (e.g., Lykkegaard & Ulriksen, 2019; Morgan et al., 2013; Nugent, et al., 2015).

A longitudinal study is much needed for gaining a deeper understanding of the process aspect that reflects the orientation toward STEM careers, through exploring the education choices that lead to STEM-related career across the lifespan within significant contexts of education and employment (Lent, et al., 2016; Lim et al., 2016; Tatum et al., 2017).

The present study aims to address this research gap, through a longitudinal study that provides insights on students' actual education choices during the transitions made from secondary school to higher education, as well as the transitions during undergraduate studies. We focus on these stages of learners' lifespan because on one hand, they play a crucial role in determining STEM employment in the future (Creed & Hughes, 2013), and on the other hand, high rates of STEM drop-out occur during higher education, particularly after first year in higher education (Bargmann et al., 2022; Miller, 2018). Our pursuit in this study is to present a broad overview of the various pathways towards a STEM or non-STEM career while paying attention to important stages in which education choices are made. Additionally, literature indicates on factors that correlate with the choice or persistence in STEM education, in particular gender, ethnicity, and choice of study and achievements in mathematics and science studies in secondary school (Lent & Brown, 2013; Sadowski & Zawistowska, 2020; Stearns et al., 2020). Thus, in this study we also pursue to identify the key characteristics that distinguish the learners along the various pathways.

Theoretical framework

This study is based on the overarching theoretical framework of the Social Cognitive Career Theory (SCCT) (Hackett & Lent, 1992; Lent et al., 1994). The SCCT consists of three interconnected models aimed at explaining interest development, choice-making, and performance and persistence in educational and vocational contexts. This framework is based on Bandura's (1986) Social Cognitive Theory (SCT), which identifies three factors that predict academic and career interests, choices and success, namely self-efficacy beliefs, outcome expectations, and goals. The SCCT model suggests that interest and choice are affected by personal attributes, particularly self-efficacy beliefs and outcome expectations, while levels of school and work performance affect the operationalization of goals (Avargil et al., 2020; Kohen & Nitzan, 2021; Tyson et al., 2007).

Over the years, SCCT's original models have been extended and applied in numerous studies (e.g., Brown et al., 2008; Lent et al., 2012; Sheu et al., 2010). In this study, we base our theoretical framework on the SCCT model of Career Self-Management (CSM) (Lent & Brown, 2013), which represents an extension of the SCCT's choice model, while relying on the same core variables (see Fig. 1).

While former SCCT models stress the content aspects of career development, that is the kinds of activity domains that influence people's career choices, the CSM model also emphasizes the process aspect, as it places focus on adaptive career behaviors employed by people

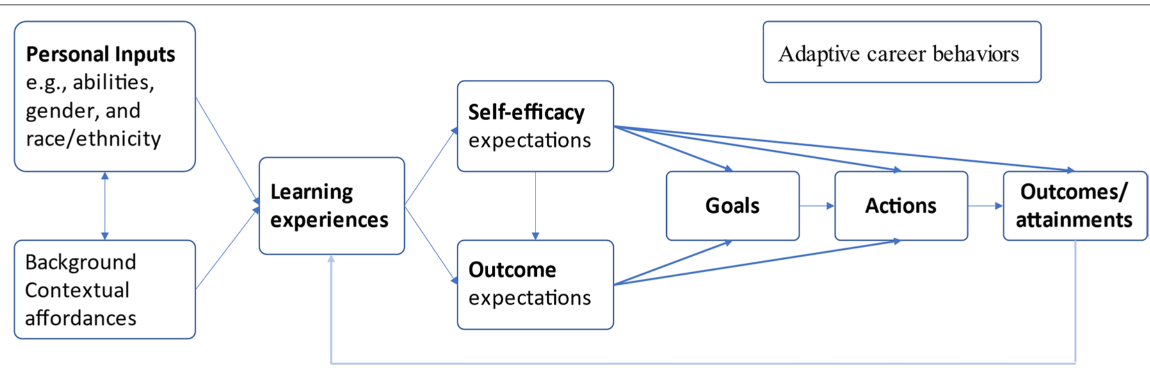

Fig. 1 The SCCT model of Career Self-Management—CSM (adapted from: Lent & Brown, 2013)

within educational and work contexts across the career lifespan. Adaptive behaviors are "behaviors that people employ to help direct their own career (and educational) development" (Lent & Brown, 2013, p. 559).

The main constructs of the CSM model, namely goals, actions, and outcomes/attainments, emphasize the transition between one's intentions to perform particular adaptive career behaviors, to decisional behaviors, and further to the outcomes of one's actions and behaviors. These constructs are affected by the core social-cognitive constructs of self-efficacy and outcome expectations, as well as person inputs, such as personality traits or person background, one's learning experiences, and environmental/contextual supports and barriers.

In what follows, we present the literature about STEM choice for study and career throughout one's lifespan, and discuss demographic and educational factors related to STEM choice for study and career, while referring to the Israeli context. As a conclusion to this theoretical review, we present the study model that is based on the CSM, taking into account key choice junctions toward STEM-related careers throughout one's lifespan as well as educational and demographic factors.

STEM choice for study and career from secondary school to higher education

A vast amount of research has been conducted on the various factors that lead to STEM persistence. In particular, researchers have pointed on personal inputs as influencing factors, such as a strong correlation between students' science identities during their secondary school studies and retention in STEM fields (e.g., Chang et al., 2020; Hazari et al., 2018). Another influencing factor reported in previous study is interest. For example, a study conducted by Tai and colleagues (2006) showed that eighth-grader students who expressed an interest in scientific careers were three times more likely to graduate from STEM-related professions than their non-interested peers.

Personal inputs were also found to be influencing during higher education studies. For example, Lytle and Shin (2020) examined the STEM engagement and persistence of about 1,200 first-year undergraduates at a STEM-focused university, and found that incremental beliefs and STEM efficacy were important predictors of STEM outcomes.

Other factors that were found to be influencing students' persistence in STEM fields are more contextually oriented. For example, a qualitative study conducted by Wu and Uttal (2020) revealed that the decision of undergraduate students to switch to, or add a STEM major, during their bachelor's degree is influenced by early STEM course preparation, supportive STEM environments, and receiving individual mentoring. Another study by Luo and colleagues (2022) investigated the influence of social agents, i.e., parents, teachers, and peers, on completion of STEM undergraduate degrees by female students, specifically in math-intensive fields, using a survey data that were collected from respondents a few years after secondary school graduation. The findings of this study point on greater likelihood to complete a STEM degree due to parental educational level and having STEM teachers as mentors, and negative association between peer-belonging and obtaining a math-intensive STEM degree.

These central personal and contextual factors are considered in the SCCT model of CSM, along with three key constructs: goals, actions, and outcomes/attainments. A recent study by Reinhold and colleagues (2018), has integrated the main constructs of the SCCT model into the Rubicon Model of Action Phases (Heckhausen & Gollwitzer, 1987), which depicts general career orientation and aspirations, through differentiating between motivational and volitional phases, i.e., the transition from the way actions are planned and carried out. The model proposes four phases, distinguished by three transition points: the first phase is pre-decisional motivation which expresses a diffuse interest in a certain career with little commitment. It involves considering the pros and cons of one's wishes, followed by making a decision point. That point leads to the pre-actional volition second phase, which accords with the choice goals phase of the SCCT framework. This phase leads to a particular goal with a growing commitment, in which a person plans the implementation of a chosen goal. Then initiation of respective actions point leads to the third actional volition phase, which accords with the SCCT framework's choice actions phase. In this phase, specific choice actions are made concerning the career goal, as one initiates goal-directed behaviors and follows them to a successful ending. The conclusion of these actions point ends up with the post-actional fourth phase, which accords with the pursuing phase of the SCCT framework. In this phase, performance and attainment within the chosen career path are observed, and the achieved outcomes are evaluated by looking back at one's behavior.

The effect of gender and ethnicity on STEM choice for study and career

Students' gender and ethnicity were found to have a significant effect on STEM choice and persistence. As compared to the general population, girls are less likely to choose STEM careers than boys (Buse et al., 2017; OECD, 2021), as are ethnic minorities (Chen & Soldner, 2013). Specifically, studies report a much stronger 'pipeline leak' of women and ethnic minorities, resulting in relatively low numbers of practitioners from these populations working in the STEM fields (Gasser & Shaffer, 2014; Minefee et al., 2018).

The gender gap in choosing STEM fields for study is not similar at the different stages in people's lifespan, yet in general, women tend to be less persistent than men in STEM fields, regardless of their academic ability (Delaney & Devereux, 2019; Fischer, 2017). The drop-out occurs mainly between secondary school and higher education studies. In secondary school, girls choose advanced matriculation electives in science and mathematics almost as frequently as boys (Delaney & Devereux, 2019). However, there are differences in the type of scientific majors chosen, with girls very much under-represented in physics and computer science, and over-represented in biology and chemistry (Friedman-Sokuler & Justman, 2016; Wegemer & Eccles, 2019). Women tend to drop out of STEM due to cultural differences and gender stereotypes that affect their employment expectations and consequently their choice of academic studies (Hill et al., 2010). In higher education, the drop out from STEM studies is quite similar between men and women (Dooley et al., 2017). However, the gender gap in STEM choice in academic studies is reflected by men dominating the STEM fields, especially physics and engineering, as reflected by at least 61% of engineering students being male (OECD, 2021), while women are well represented in biology and chemistry representing 52% of new entrants to the fields of natural sciences (OECD, 2021).Upon graduation, the gender gap still exists, with women less likely to earn a bachelor's degree in STEM (Card & Payne, 2017, 2021). In spite of being a majority among undergraduates, on average, 55% of new entrants to tertiary education in 2019 were women (OECD, 2021), while they make up less than 50% of STEM degrees in general, and less than 30% of computer science and engineering degrees specifically (Card & Payne, 2021; OECD, 2016, 2021). According to the National Science Board (2018), about 47% and 59% of the recipients of bachelor's degrees in chemistry and biology, respectively, are women.

With respect to ethnic minorities, despite a similar interest in STEM, the presence of ethnic minorities in STEM subjects and high-level mathematics studies in secondary school, which are the basis for a future interest in STEM studies in higher education, is insufficient as compared to the general population (Ma & Liu, 2017; NSB, 2017). Accordingly, ethnic minority students are 1.37 times less likely to study advanced mathematics or science major in secondary school than the general population (Bottia et al., 2018), and this probably has a lasting effect that manifests choice of the STEM professions made when choosing a path in higher education (approximately 1.35 times less), and completion of a bachelor's degree (approximately 1.51 times less) (Bottia et al., 2018; NSB, 2014). This gap between interest and actual choices can be explained, among other factors, by an insufficient academic preparation (Ma & Liu, 2017).

Among ethnic minorities in Israel, the situation is different than outlined above, so we first describe the minority group in terms of ethnicity, which is the Arab population. The Israeli population comprised two main ethnicities, of which the Jews constitute the majority (approximately 75%), and Arab minority of approximately 21% of the general population (Friedman-Sokuler & Justman, 2020). Both ethnicities are served by a centralized education system administered by the National Ministry of Education, which oversees, among other things, the curriculum, structure, teacher supervision and budget (Friedman-Sokuler & Justman, 2020). In both elementary and secondary schools, most Arab students study in Arabic-language schools that follow the same curriculum in mathematics and science as the Hebrew-language schools.

According to Ayalon (2002), and contrary to the situation observed among other ethnic minorities worldwide, there are high percentages of Arab students in Israel who choose STEM subjects in secondary school, which is the result of few options of elective subjects in non-STEM fields in Arab schools. Thus, students in Arabic-language schools in Israel are more likely to take STEM advanced-level elective subjects in secondary school as compared to students in Hebrew-language schools. According to data retrieved in 2013 by Fuchs (2017) from the Israeli CBS, approximately 44% of Arab students study biology or chemistry, as compared to only 19% of the Jewish students. In addition, about 32% of Arab students study other STEM fields, as compared to 27% of the Jewish students. In general, about 76% of Arab students study advanced-level elective subjects in STEM in secondary school, as compared to only 46% of the Jewish students. Israel also has a clear policy of promoting and integrating minorities in scientific-technological professions, which is absent from other countries such as the United States, Germany, and Sweden (Zehavi & Breznitz, 2017).

Despite the large exposure of Arab students to STEM studies in secondary school, and government efforts to integrate minorities into STEM fields, their representation in STEM studies in higher education is inadequate, with only 25% of the Arab students choosing STEM subjects, as compared to 41% of the Jewish students (Fuchs, 2017). It is important to note that about one-quarter of Arab Israeli students study abroad, most of them men (Kraus et al., 1998), while data from the CBS exists only for Israeli academic institutions.

The effect of secondary mathematics and STEM major on STEM choice for study and career

Studies show that proper academic preparation for STEM studies is essential for the prevention or reduction of the drop-out rate from STEM studies (Chen & Soldner, 2013). Secondary school mathematics has been found to provide a good foundation for later STEM studies and entry into higher education (Kohen & Nitzan, 2022; Long et al., 2012; Redmond-Sanogo et al., 2016; Sadler et al., 2014). Studies indicated that lack of substantial mathematics skills often prevents students from choosing STEM fields to study (Sadowski & Zawistowska, 2020), as it is perceived to be a basic subject for all other sciences (Li, 2013).

Mathematics success in secondary school is considered a key factor in developing and promoting students' confidence in their ability to pursue a STEM career, as well as a good predictor of future STEM academic and professional success (Cannady et al., 2014; Holmes et al., 2018; Hossain & Robinson, 2012; Lee et al., 2015; Lichtenberger & George-Jackson, 2013; Sahin et al., 2018; Wang, 2013). For example, Maltese and Tai (2011) revealed that students who took advanced mathematics courses in secondary school, such as completing geometry in 9th grade instead of 10th grade, were more likely to pursue STEM in higher education. A longitudinal study revealed that students who excelled in mathematics in secondary school had twice the likelihood of being employed in STEM professions than those who had low mathematics achievements (Anlezark et al., 2008).

A previous study conducted by the authors explored the extent to which students' excellence in mathematics impacts their future academic and career choices and success in STEM fields. Taking into consideration the level of mathematics studied (elementary, standard, and advanced) and the level of success in secondary mathematics (Low/fail, intermediate, good, and excellent), findings indicated that studying advanced mathematics in secondary school, rather than success in secondary mathematics, is the best predictor of completing a STEM bachelor's degree, succeeding in a STEM bachelor's degree, and choosing STEM as a career (Kohen & Nitzan, 2022).

In addition to secondary mathematics success, secondary school science studies set the basis for STEM studies in higher education from two directions. First, choosing a STEM major in secondary school serves to encourage students' aspirations for future studies and careers in STEM. On the opposite direction, students' future employment orientation affects students' interest in majoring in science in secondary school (Holmes et al., 2018; Lichtenberger & George-Jackson, 2013; Maltese & Tai, 2011). Therefore, students who wish to pursue a STEM career may become interested in these fields in secondary school, so they can better prepare themselves for future studies in these fields (Sadler et al., 2012).

The study model

In this study, we propose to conceptualize the three main components of the CSM model by Lent and Brown (2013), namely choice goals, choice actions, and pursuing, as related to the various phases through which individuals follow in making career decisions at different stages of their lives, from secondary school, to the first year of undergraduate studies, and to graduating a bachelor's degree.

The nature of the data for this study, obtained from the CBS in Israel, allowed us to get indication of one's actual education choices of STEM or non-STEM field of study from secondary school to bachelor's degree graduation. Additionally, while the nature of the data obtained did not allow us to explore personal inputs, such as one's abilities or disabilities, nor the self-efficacy of outcome expectations of the research sample, the study does explore demographic and educational factors influencing the various phases of the model. Figure 2 presents the model implemented in our study, referring to the context of STEM career orientation in various periods in lifespan.

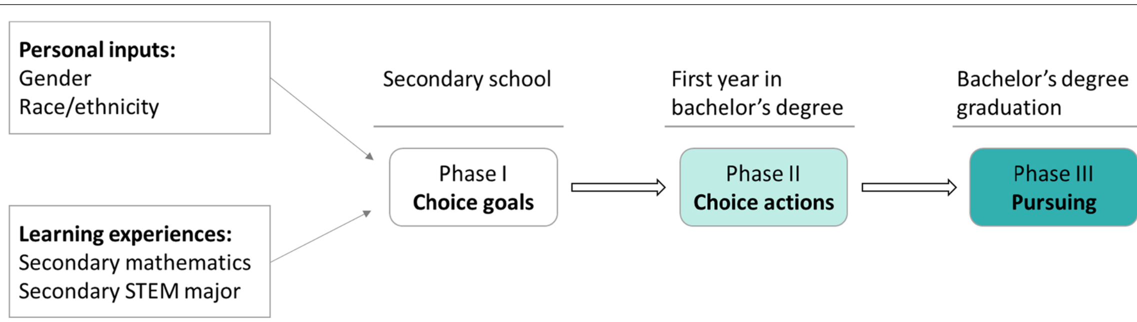

Fig. 2 The study model, based on the CSM model of Lent and Brown (2013)

Accordingly, the phases in this study are defined as follows: the first phase of choice goals refers to choosing STEM as a major in secondary school, namely a pre-active interest in STEM. This phase represents a little commitment towards a particular career, based on students' ability and performance. The choice of STEM as a major in secondary school was found to have a significant impact on the likelihood that students reject, persist in, and enter STEM fields in higher education (Engberg & Wolniak, 2010; Tai et al., 2006). The second phase of choice actions refers to choosing STEM as a major in the first year of higher education. It represents the actions taken in an effort to realize the students' chosen careers, also based on their ability and performance. This phase was specifically defined in this study, as it is considered a critical step towards choosing a career path (Creed & Hughes, 2013; Lehmann & Konstam, 2011). Previous studies indicate that the most significant 'leakage' among students who had an early interest in STEM studies occurs during the undergraduate study period (Witteveen & Attewell, 2020), when approximately 48% of the students who start in the STEM path drop out of these fields by the end of the degree (Chen & Soldner, 2013). Finally, the third phase, that is pursuing, refers to obtaining a bachelor's degree in a STEM field. This phase indicates attainment and perseverance in one's chosen career as a potential future occupation, since STEM graduates are more likely to enter STEM-related careers (Kohen & Nitzan, 2021).

Aim and research questions

The aim of the present study is to explore the process of STEM career decision-making from the view of the SCCT model of CSM. We aim to explore the STEM career orientation through characterizing different pathways towards a career in STEM or non-STEM fields according to important stages in the lifespan, as well as examining demographic and educational variables 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 demographic and educational variables?

Methodology

Secondary mathematics and a STEM major in Israel

In the 10th grade, Israeli students are required to choose a major subject, usually at an advanced level. Most schools in Israel offer a wide range of major subjects, including STEM and non-STEM subjects. There is also a division into three levels of mathematics studies, influenced by students' achievements in the 9th grade and the teachers' recommendations, each with different levels of depth and topics covered. The elementary level, which is the minimal requirement for obtaining a matriculation certificate, requires skills that are mainly applied techniques. The standard level provides a solid foundation of mathematical skills and knowledge, as subjects are studied in a deeper and broader manner, and include new and more complex subjects, such as Euclidean geometry and Analytical geometry. The advanced level is the highest level in the Israeli educational system, with an emphasis on developing mathematical-scientific thinking, aimed at guiding students towards STEM studies, and includes new and more complex subjects, such as Vectors and Complex numbers.

There is no threshold for choosing a science major, that is, studying at a particular mathematical level is not a prerequisite for choosing a science major. However, when calculating the threshold for university admission in Israel, studying at the standard and advanced levels gives students a relative numerical bonus, which is especially helpful for students who are considering entering the STEM fields in higher education.

Higher education studies in Israel

There are ten universities and dozens of colleges in Israel that offer bachelor's degrees. Bachelor's degrees in Israel typically last three to four years. In the first year of study, students take courses related to their major, depending on what field of study they choose. Typically, first or second year courses involve more basic subjects, such as linear algebra, physics, and computer science for STEM students, and few general courses, such as liberal arts, sports, or Jewish studies. During the following years, students take more advanced courses that relate directly to their majors.

Participants

A base population of 534,590 Israeli secondary school students was sampled for this study. Data were obtained from the Israeli Central Bureau of Statistics (CBS), using systematic sampling containing all secondary school graduates over one and a half decade, in the years 2001, 2006, 2011, 2015, and 2017. The Israeli CBS has access to national administrative data, which allowed us to track student achievement and demographic data from secondary school to university graduates, enabled us to map the different pathways a learner goes through toward STEM career, as well as the learners' characteristics in each pathway. The second group of participants included

308,041 students who belonged to the base population and were in the first year of undergraduate studies in institutions of higher education in Israel between 2001 and 2017. The third group of participants, drawn from the same base population, consisted of 245,113 graduates of higher education institutions in Israel between 2001 and 2017.

Observed variables

The codebook that guided the analysis comprised demographic data, including gender and ethnicity, and educational data, including level of secondary school mathematics, type of science major, and the level of success in mathematics and science in secondary school. Based on the matriculation exam in mathematics and science, this study defined success on four levels: Excellent, which includes students with grades between 91 and 100; Good, which includes students with grades between 81 and 90; Intermediate, which includes students with grades between 61 and 80; and Low/fail, which includes students with grades below 60. According to the Ministry of Education in Israel, it is an acceptable distribution to divide grades according to various levels (Ministry of Education, 2016).

The definition of the STEM subjects, which are based on definitions from the educational literature (Honey et al., 2014) and have also been validated by experts, are as follows: STEM subjects in secondary school include physics, chemistry, biology, and computer science; STEM subjects in higher education refers to the following subjects: mathematics, statistics and computer sciences; the physical sciences; the biological sciences; agriculture; medicine; or engineering and architecture. The remaining subjects were defined as non-STEM subjects. Table 1 presents the distribution of all predictor variables, by the base population for this study.

Data analysis

In response to the first RQ, aiming to identify possible pathways for obtaining STEM and non-STEM bachelor's degrees, we designed a three-tier tree which represents the three stages of choice throughout one's lifespan, starting from secondary school, moving on to the first year of bachelor's degree, and graduation with a bachelor's degree at the final stage. Frequencies and Chi-square tests were applied, as well as a Cramer's V test to examine the strength of the distribution. The first tier represents the major subject studied in secondary school, either STEM or non-STEM. In the second tier, each of

Table 1 Distribution by the predictor variables

			N	%	Total
Demographic characteristics	Gender	Male	238,797	44.7%	534,587
		Female	295,790	55.3%	
	Ethnicity	Jewish	431,908	82.7%	522,160
		Arabic	90,252	17.3%	
Secondary school	Mathematics level	Elementary	251,569	52.1%	482,606
		Standard	137,060	28.4%	
		Advanced	93,977	19.5%	
	Mathematics success	Excellent	104,061	26.3%	396,233
		Good	97,627	24.6%	
		Intermediate	135,842	34.3%	
		Low/fail	58,703	14.8%	
	Major field of study	STEM	257,051	48.1%	534,590
		non-STEM	277,539	51.9%	
	STEM major success	Excellent	43,284	20.0%	215,931
		Good	66,717	30.9%	
		Intermediate	88,577	41.0%	
		Low/fail	17,353	8.0%	
First year in higher education	Field of study	STEM	92,245	29.9%	308,005
		non-STEM	215,760	70.1%	
Bachelor's degree	Field of study	STEM	68,995	28.1%	245,113
		non-STEM	176,118	71.9%	

The total *N* is not similar in relation to all predictor variables, since a) as some variables explored have missing data, percentages were calculated based on valid data, b) for the variables relating to higher education, data are based on two base populations, each reflects different sample size (see elaboration on the participants section) the first two branches is divided according to the choices made during the first year of higher education. This tier was obtained using a Chi-square test which combined a descriptive distribution of STEM or non-STEM subjects studied in secondary school and in the first year of higher education. The third tier builds on the previous two, representing eight pathways, from secondary school to obtaining a bachelor's degree. This tier was obtained by performing 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 the first year of higher education and the completion of a bachelor's degree. Thus, the three-tier tree was created, representing eight different pathways to STEM or non-STEM graduation with bachelor's degrees. Figure 3 illustrates the three-tier tree of pathways towards STEM or non-STEM degrees.

Pathways were ranked from one to eight, so a higher number indicates persistence in choosing STEM over the years and completion of a STEM degree. The internal ranking of these pathways was based on the degree of persistence and selection sequence in STEM over the three stages of life examined. Hence, learners in pathway #8 were awarded the highest rank, since they persevered in the STEM professions in all three stages examined and completed a STEM degree. Pathway #7 was ranked lower than pathway #8, since learners in this pathway showed persistence toward STEM studies only in higher education, but not in secondary school. Pathway #6 was ranked higher than pathway #5, since although learners in these pathways graduated with a STEM degree in higher education, learners in pathway #6 also studied this profession in secondary school, thus showing more persistence. The four lower pathways (#4 down to pathway #1) were defined in a similar fashion, ending with learners in pathway #1 who persevered in the non-STEM professions in all three stages.

In response to the second RQ, aiming to map the characteristics of each pathway by demographic (gender and ethnicity) and educational (mathematics level, mathematics success, type of science major, and science major success) variables, we created a new variable, the "choice variable", which includes eight values based on the eight pathways described above. Each learner who completed a bachelor's degree was

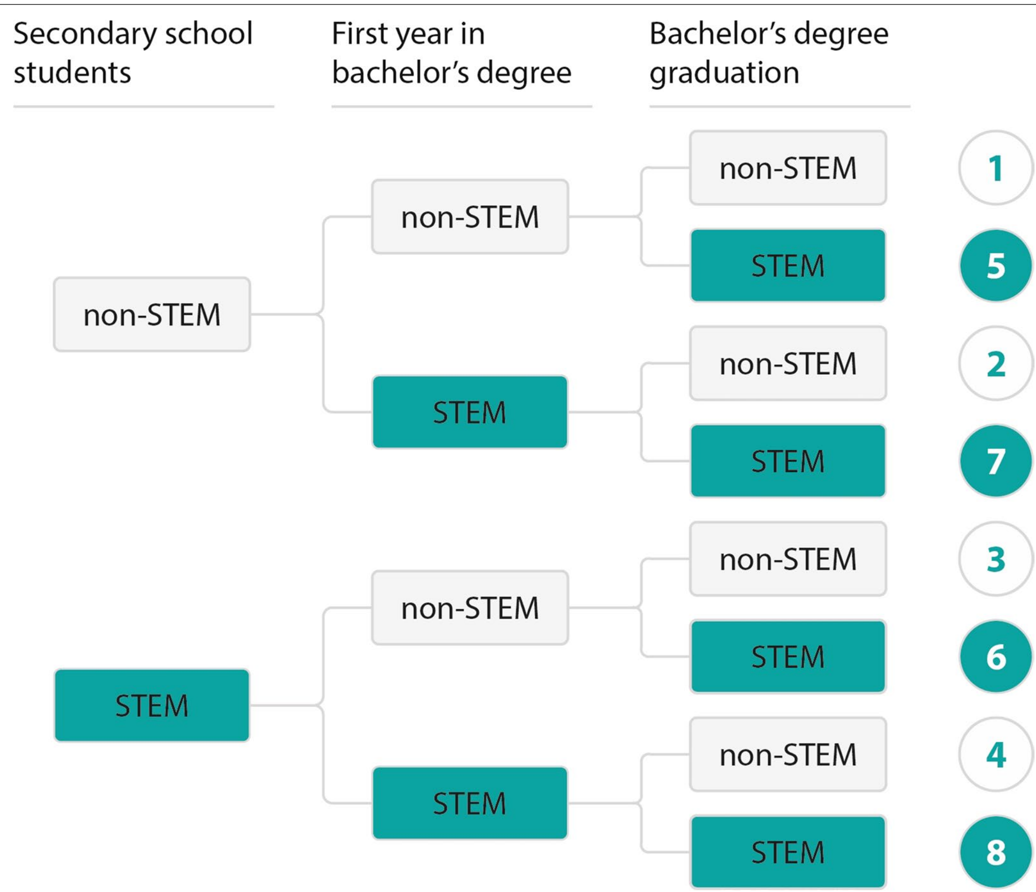

Fig. 3 The three-tier tree, representing eight pathways toward a STEM or non-STEM profession

assigned one value out of the eight, according to their path throughout the three periods investigated. For mapping the characteristics for each of the eight different pathways, Chi-square tests were conducted in order to obtain a 2D table describing a combined descriptive distribution between the choice variable and each of the demographic and educational variables. Additionally, a Kruskal–Wallis analysis of variance (ANOVA) was performed, for analyzing the statistical differences between the different pathways, in relation to each of the demographic and educational variables. All the differences were considered significant at a 5% level.

Results and discussion

The results presented below begin with the mapping of the various possible pathways to STEM and non-STEM bachelor's degrees. We then characterize the various pathways, based on the demographic and educational variables, and explore how the different pathways differ depending on the background variables.

Eight pathways to STEM or non-STEM degrees

The three-tier tree presented in Fig. 3 represents eight different pathways to STEM and non-STEM bachelor's degrees by three stages of choosing a course of study, STEM or non-STEM, starting from secondary school, moving on to the first year of higher education, and ending with graduation with a bachelor's degree. The following figure presents the distribution of choice of STEM or non-STEM in each of the life periods examined for this study population (Fig. 4). The figure includes the educational pathways of 308,005 Israeli secondary school students who also began academic studies. These students are about 58% of the base population of 534,590 Israeli secondary school students included in this study.

Figure 4 displays a similar distribution of STEM and non-STEM choices among secondary school students, with STEM fields favored (57.2%). For those who studied STEM or non-STEM in secondary school, a significant and strong correlation was found between the choice of a STEM or non-STEM field in the first year of higher education and the completion of a bachelor's degree in STEM or non-STEM fields (Cramer's

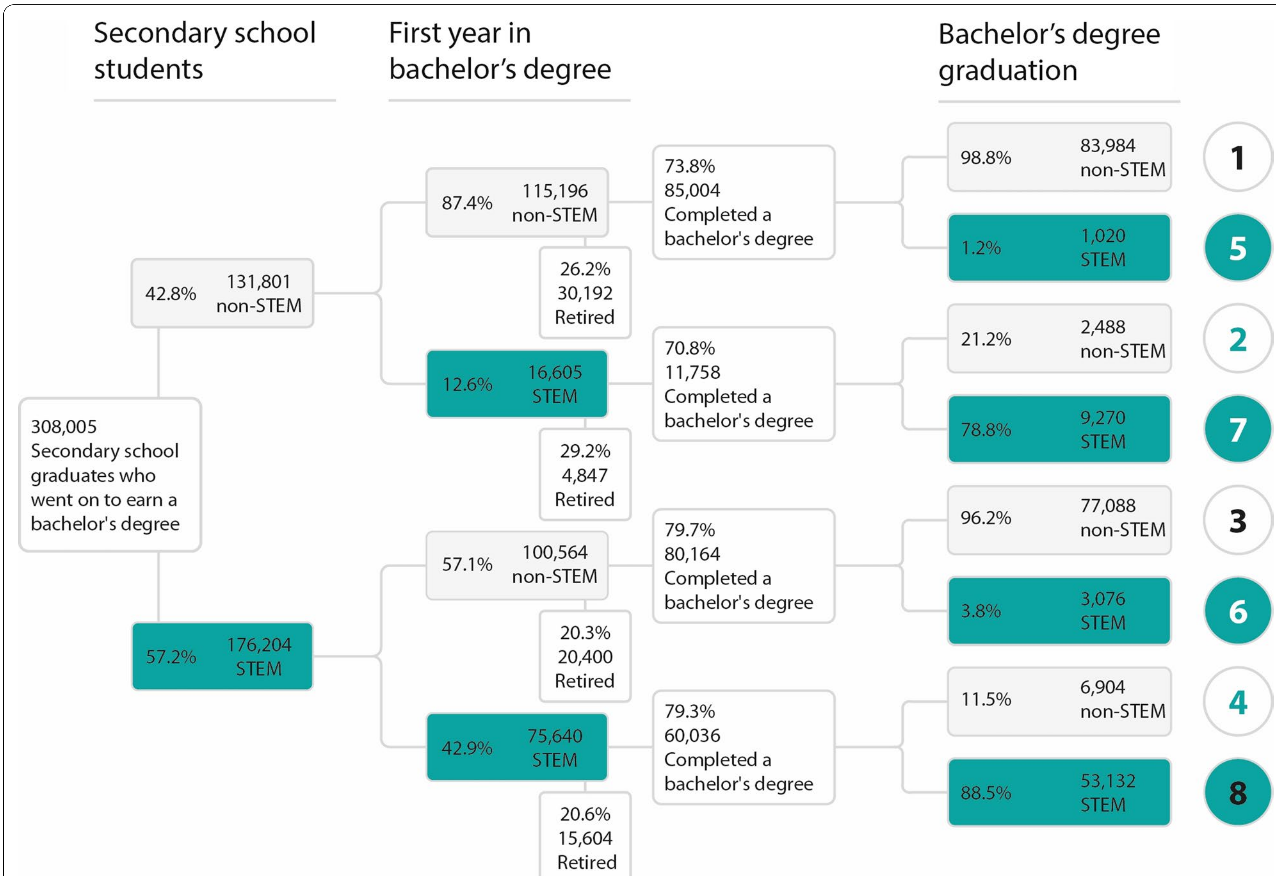

Fig. 4 Distribution of choice in STEM or non-STEM field during significant periods in life

$V = 0.82$, $p < 0.001$ for STEM secondary students, and Cramer's $V = 0.86$, $p < 0.001$ for non-STEM secondary students), indicating the effect of a choice of major in secondary school on the choice of STEM or non-STEM fields in higher education. Specifically, the distribution of first year undergraduate students in the STEM and non-STEM fields is not symmetrical. Almost 43% of those who studied STEM subjects in secondary school choose a STEM field in their first year of higher education, compared with less than 13% of those who studied non-STEM, that is, 3.4 times more. The distribution of graduates revealed an ongoing impact of the choices made in school. Approximately 85% of STEM graduates studied a STEM major in secondary school, compared with only 15% who studied a non-STEM major, that is, 5.5 times more.

When focusing on absolute numbers of students in the study sample who completed a bachelor's degree, the three-tiered tree indicates three dominant pathways. Pathway #1 reflects about 35% ($N = 83{,}984$) of students who persisted in choosing non-STEM fields from secondary school to a bachelor's degree graduation. Pathway #8 reflects the 22% ($N = 53{,}132$) of persistent students who followed a STEM path from secondary school to a bachelor's degree graduation. Finally, pathway #3, which reflects approximately 33% ($N = 77{,}088$) of students, may be the most notable pathway, since it demonstrates the largest 'leak' that occurs from STEM studies in secondary school towards non-STEM studies in higher education and graduation. This finding regarding the leakage demonstrated in pathway #3, was found to be consistent with previous studies (Engberg & Wolniak, 2010; Tai et al., 2006). Therefore, an examination of the characteristics of learners in pathway #3 is critical for the attempt to narrow the leak.

The other pathways, where transitions took place during undergraduate studies, represent only small percentages of graduates. Pathways #2 and #4, representing the move from STEM to non-STEM, include approximately 4% of the graduates, and pathways #5 and #6, representing the move from non-STEM to STEM, include only 1.7% of the graduates. Pathway #7, representing students who studied a non-STEM field in secondary school and made a shift into a STEM track in higher education, includes approximately 4% of the graduates. Even though these pathways make up only 9.6% of undergraduate students, they may make a significant contribution to increasing the number of STEM practitioners, as it is possible to produce thousands of STEM graduates annually, even with a slight increase in movements towards STEM pathway (Miller, 2018). To that end, this study examines the characteristics of learners in all pathways.

Learners' characteristics in the eight pathways

In this section, we characterize the eight pathways based on demographic (gender and ethnicity) and educational (mathematics level, mathematics success, type of science major, and science major success) characteristics. First, using a Kruskal–Wallis analysis of variance (ANOVA), we statistically validate the differences in distribution within each characteristic between the various pathways. Second, we describe the distribution of the various characteristics within each pathway. Finally, we describe the distribution of the various characteristics, while comparing between the different pathways. Appendix A shows the distribution of demographic (Table 5) and educational (Table 6) characteristics according to the eight pathways, respectively.

Comparing the pathways by learner characteristics

The figures below illustrate the pairwise comparisons of the pathways for each of the demographic (Fig. 5a, b) and educational (Fig. 6a–c) variables. Each line in the figure represents the comparison between two pathways, in relation to one characteristic. For example, the line between pathways #1 and #3 in Fig. 3a represents the significant difference between these pathways in their distribution by gender.

The type of line connecting each two pathways indicates the degree of significance between them, according to the legend within the diagrams, i.e., a blue line represents a significance at the 0.001 level, a dashed line represents a significance at the 0.01 level, and a black line represents a significance at the 0.05 level. A lack of connecting line between two pathways indicates a lack of significant difference in the distribution of the variable between them.

According to Fig. 5a, there are more women than men in all the pathways that end in non-STEM fields, i.e., pathways #1, #2, #3, and #4, as well as in pathway #5,

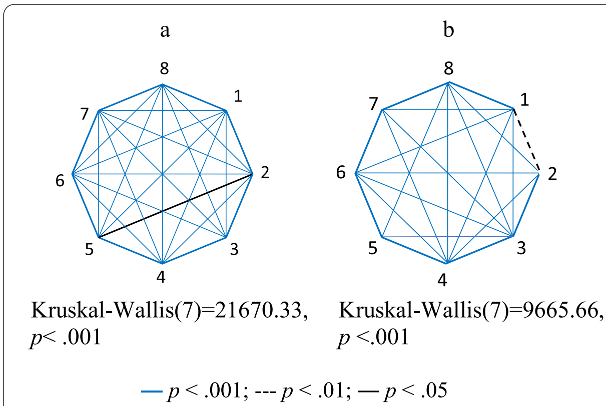

Fig. 5 Differences in distribution by **a** gender, and **b** ethnicity

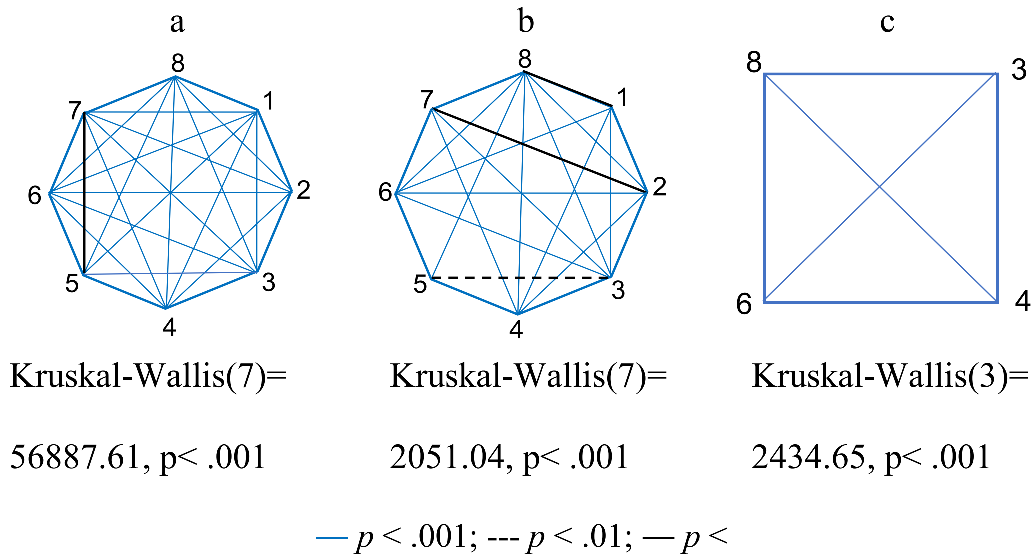

Fig. 6 Differences in distribution by **a** mathematics level, **b** mathematics success, and **c** science major success

which represents STEM undergraduates who did not study STEM in secondary school and switched from a non-STEM to a STEM field after their first year of higher education. The most significant gap in favor of women was found in pathway #1, followed by pathways #3 and #5, then in pathway #2, and finally in pathway #4. For the pathways that end in STEM fields, opposite gaps in favor of men were found, mostly in pathway #8, followed by pathways #7, and finally in pathway #6. Indeed, previous research has indicated that gender is a significant factor in the choice and persistence in STEM fields, particularly in higher education (Buse et al., 2017; Delaney & Devereux, 2019). The barrier toward persistence in STEM studies among women is explained in literature by several reasons, including stereotypes (Hill et al., 2010) or a sense of low self-confidence in their ability to succeed in these fields (Stearns et al., 2020).

According to Fig. 5b, compared to their relative size in the population, in pathways #3 and #4 which reflect those who started STEM in secondary school and ended with a non-STEM bachelor's degree, there is a significantly higher presence of Arab students, as compared to the other pathways, in which there is a majority of Jews. The most significant gap in favor of Arab students was found in pathway #4, representing graduates who began STEM studies in higher education but completed a non-STEM degree. These findings align with the literature about ethnic minorities in Israel and abroad, according to which there is insufficient representation of STEM ethnic-minorities students, particularly in higher education (Ma & Liu, 2017; NSB, 2017). Yet, as revealed in the findings above, this bias toward non-STEM studies occurs among Arab students in Israel only toward higher education, as in secondary school there is an adequate representation of Arab students in STEM majors (Ayalon, 2002; Fuchs, 2017).

According to Fig. 6a, in most pathways which start with a STEM secondary school major, namely pathways #4, #6, and #8, there is a majority of advanced-level students in mathematics. The most significant gap in favor of advanced mathematics studies was found in pathway #8, the STEM persistence, followed by pathway #6, which also ended with a STEM degree, and the lowest gap, in favor of advanced mathematics studies, was found in pathway #4 which ended with a non-STEM degree. On the contrary, for all pathways which start with a non-STEM secondary school major, i.e., pathways #1, #2, #5, and #7, there is a gap in favor of elementary level students in mathematics, as the most significant gap was found in pathway #1, the non-STEM persistence. Finally, the only pathway where there was a significant gap in favor of standard level students in secondary mathematics was pathway #3, which starts with STEM major in secondary school, switch to non-STEM fields in higher education, and ends with a non-STEM degree.

The distribution by mathematics level describe above, is in line with previous studies emphasizing the contribution of mathematics level on choice and persistence in STEM fields (e.g., Kohen & Nitzan, 2022; Sadler et al., 2014). For example, in Bowyer and Darlington (2016), college students studying physics claimed that more advanced mathematics courses in secondary school would have helped them be more successful in their undergraduate physics courses.

According to Fig. 6b, in all pathways that start with STEM secondary major, that is pathways #3, #4, #6, and #8, there is a greater presence of learners who excel in mathematics. In particular, the most significant gap in favor of those who excel in mathematics studies was found for pathway #8, the STEM persistence, followed by pathways #4 and #6, and finally for pathway #3. Regarding the pathways that start with non-STEM secondary major, i.e., pathways #1, #2, #5, and #7, there is a greater presence of learners who score the intermediate level in mathematics. The most significant gap in favor of those who score the intermediate level was found in pathway #2, who chose STEM studies only for the first year of undergraduate studies and graduated with non-STEM degrees. These findings are supported by the research literature (e.g., Sadowski & Zawistowska, 2020), and are compatible with the above findings regarding mathematics level, as advanced mathematics studies and excellence in mathematics—both have an ongoing impact on STEM choice in higher education.

According to Fig. 6c, the only pathway that presents a greater presence of learners who excel in secondary STEM major is pathway #8, which represents the persistent STEM learner. Pathways #4 and #6 demonstrate a greater presence of learners who score the good level in secondary STEM major, with no significant difference between these two pathways. Finally, pathway #3 demonstrated a greater presence of learners who score the intermediate level in secondary STEM major. These findings are in line with previous findings that indicated the importance of success in secondary STEM studies on continued choice and perseverance in STEM (Sadler et al., 2012).

The distribution of learners' characteristics within and between pathways

This section is divided into two sub-sections as follows: (a) mapping the characteristics of the dominant pathways: #1 (the non-STEM pathway), #8 (the STEM pathway), and #3 which includes those who chose STEM in secondary school but switched to a non-STEM path in higher education; (b) mapping the secondary pathways which started with a STEM (#4 and #6) or non-STEM (#2, #5, and #7) secondary major.

For each sub-section, after describing the distribution within each pathway according to the various characteristics, we use bar-charts to illustrate the distribution between the pathways in each sub-section. We divided the comparisons between the pathways as follows: Bar-charts for the demographic variables, bar-charts for the educational variables in mathematics, and bar-charts for the educational variable in secondary STEM major.

Two steps were needed to calculate the percentages for each variable in the bar-charts, the first step was normalizing the distribution beyond the differences in group size by calculating the percentage ratio of the value presented in relation to the number of subjects in that variable. In the second step, a comparison was performed between the pathways presented, so that the value displayed in each pathway was compared to the values displayed in the other pathways and sum to 100%.

Distribution by dominant pathways

We first present Table 2, describing the distribution within each of the three dominant pathways according to various demographic and educational characteristics of learners. Then, for comparing between the three dominant pathways, Fig. 7a illustrates the three dominant pathways and serves as a legend for the charts that follow. Figure 7b–d, illustrates the distribution between the three dominant pathways for each of the demographic and educational characteristics, that is the total distribution of each characteristic for the three pathways accounting for 100%.

A Kruskal–Wallis test revealed significant differences between the three dominant pathways in all characteristics. Regarding the demographic characteristics (Fig. 7b), pathways ending with a non-STEM degree (#1 and #3) have a higher representation of women as compared to men. On the other hand, pathway #8, the STEM path, has a higher representation of men. This finding is consistent with the research literature, according to which women are less likely to choose the STEM track in higher education as compared to men (Card & Payne, 2021; Delaney & Devereux, 2019). When looking at distribution by ethnicity, a different picture was observed. There is a greater presence of Jews in pathways #1 and #8 compared to Arab students, which are pathways that have not had a 'leak' over time. In contrast, there is a greater presence of Arab students in pathway #3, which represents a leak from STEM in secondary school to non-STEM in higher education.

These findings are consistent with the research literature in the field, indicating a gender gap in favor of men in choosing STEM studies at different stages of life and completing a STEM bachelor's degree (Delaney & Devereux, 2019). In addition, unlike ethnic minorities in other countries, whose presence in STEM majors is insufficient even in secondary school (Ma & Liu, 2017; NSB, 2017), learners from the Arab minority in Israel are more likely to study STEM in secondary school but graduate with a non-STEM bachelor's degree, which is consistent with previous studies on ethnic minorities in Israel. At the secondary school stage, most Arab learners choose the STEM path, mainly due to the little variety

Table 2 Distribution of characteristics within dominant pathways

Distribution within pathways		Dominant pathways		
		Pathway #1 non-STEM — non-STEM — non-STEM	**Pathway #3** STEM — non-STEM — non-STEM	**Pathway #8** STEM — STEM — STEM
Gender	Men vs. Women	The number of women is approx. 2.9 times more than men	The number of women is approx. 1.8 times more than men	The number of men is approx. 1.7 times more than women
Ethnicity	Jews vs. Arabs	There are 2.4 times more Jewish students than Arab students	The number of Arab students is almost twice as large as that of Jewish students	The number of Jewish students is approx. 1.3 times more than Arab students
Mathematics level	Advanced vs. Standard vs. Elementary	The number of elementary students is approx. 2.5 and 13.5 times more than standard and advanced students, respectively	The number of standard students is approx. 1.6 times more than elementary and advanced students	The number of advanced students is approx. 8.2 and 2.2 times more than elementary and standard students, respectively
Mathematics success	Excellence vs. Good vs. Intermediate vs. Low/fail	The number of intermediate students is approx. 1.1 times more than good and excellent students, and approx. 2.7 times more than Low/fail students	The number of Low/fail students is approx. 4.1 times less than intermediate, good, and excellent students	The number of excellent students is approx. 1.5, 2.1, and 11.5 times more than good, intermediate, and Low/fail students, respectively
Science major success	Excellence vs. Good vs. Intermediate vs. Low/fail	Not relevant to this pathway	The number of intermediate students is approx. 1.2, 2.2, and 9 times more than good, excellent, and Low/fail students, respectively	The number of excellent and good students is approx. 1.3 and 16.2 times more than intermediate and Low/fail students, respectively

of alternative major subjects in Arab-language schools (Ayalon, 2002). However, Arab students in Israel are not sufficiently represented in higher education in general, and in STEM studies in particular (Fuchs, 2017).

Regarding the educational characteristics in mathematics (Fig. 7c), most students who persist in the STEM path (#8) study advanced mathematics and excel in mathematics in secondary school. An opposite effect is evident with students in the non-STEM path (#1), of whom most students study at the elementary level of mathematics and get an intermediate grade in the matriculation exam in mathematics in secondary school. However, in pathway #3, presenting the leakage from STEM in secondary school to non-STEM studies in higher education, most students study at the standard level of mathematics in secondary school, and get an intermediate grade in the matriculation exam in mathematics.

Indeed, mathematics studies in secondary school were found to have an impact on the future choice of STEM subjects (e.g., Holmes et al., 2018; Kohen & Nitzan, 2022; Sahin et al., 2018). In light of this, the persistent pathways (#1 and #8) present an appropriate distribution, when high performance in secondary mathematics relate to the STEM path (#8), and low performance in secondary mathematics relate to the non-STEM path (#1). However, pathway #3 brings about an intriguing phenomenon. About 29% of the students in this path study advanced mathematics and therefore supposedly have the potential to continue to STEM studies, as well as 44% of the students in this path who study mathematics at a standard level, and therefore to some extent, also have the potential to continue STEM studies. In addition, the degree of success in mathematics does not appear to be a significant variable in the characterization of this path.

That is, there seems to be salient feature in this path, beyond the level of mathematics studied and the level of success in mathematics that has an impact on the transition from STEM studies in secondary school to non-STEM studies in higher education. When comparing the secondary STEM major variables of students in path #3 with students' choice in path #8 (Fig. 7d), both of whom began with STEM major studies in secondary school, we discovered that one of the differences between these two groups of students is that most students in path #8 excel in their secondary school STEM major and most students in path #3 achieve only intermediate grade in the matriculation exam in STEM major. It is possible that the experience of success in secondary school STEM subjects is one of the factors influencing the choice of STEM or non-STEM subjects in higher education. This finding may be explained by the SCCT framework, according to which orientation toward career choice is affected by personal attributes, particularly self-efficacy beliefs (Avargil et al., 2020; Tyson et al., 2007). Therefore, the experience of success in STEM studies in secondary school can encourage students to continue choosing STEM subjects in higher education.

In addition, the distribution of the types of secondary STEM major for the dominant pathways, #3 and #8, revealed that students who study physics and computer science are more likely to follow path #8, that is, persevere in STEM studies throughout their lifespan, as well as students who study chemistry. However, students who study biology are more likely to follow path #3, that is, switch to non-STEM studies in higher education. This finding is consistent with previous findings (e.g., Card & Payne, 2017, 2021), which show that studying physics or computer science are better predictors of further STEM studies and employment in STEM, as compared to studying biology.

The distribution of secondary pathways beginning with a secondary STEM major

Similar to the above analysis, we first present Table 3, describing the distribution within the two secondary pathways beginning with a STEM major in secondary school according to various demographic and educational characteristics of learners. Then, for comparing between these secondary pathways, Fig. 8a illustrates the relevant secondary pathways and serves as a legend for the charts that follow. Figure 8b, c, and d illustrates the distribution *between* the two secondary pathways for each of the demographic and educational characteristics.

A Kruskal–Wallis test revealed significant differences between the secondary pathways beginning with a STEM secondary major in the demographic characteristics and in the mathematics educational characteristics only. Regarding the demographic characteristics (Fig. 8b), findings are similar to those described regarding the three dominant pathways. That is, those who show more persistence towards STEM in higher education, i.e., learners in pathway #6, are predominantly male and Jewish as

(See figure on next page.)

Fig. 7 The characteristics of the three dominant pathways: **a** illustration of the dominant pathways, #1, #3, and #8; **b** the distribution of the demographic characteristics between the dominant pathways; **c** the distribution of the educational characteristics in mathematics between the dominant pathways; **d** the distribution of the educational characteristics in STEM major between the dominant pathways which started with STEM in secondary school, i.e., pathways #3 and #8

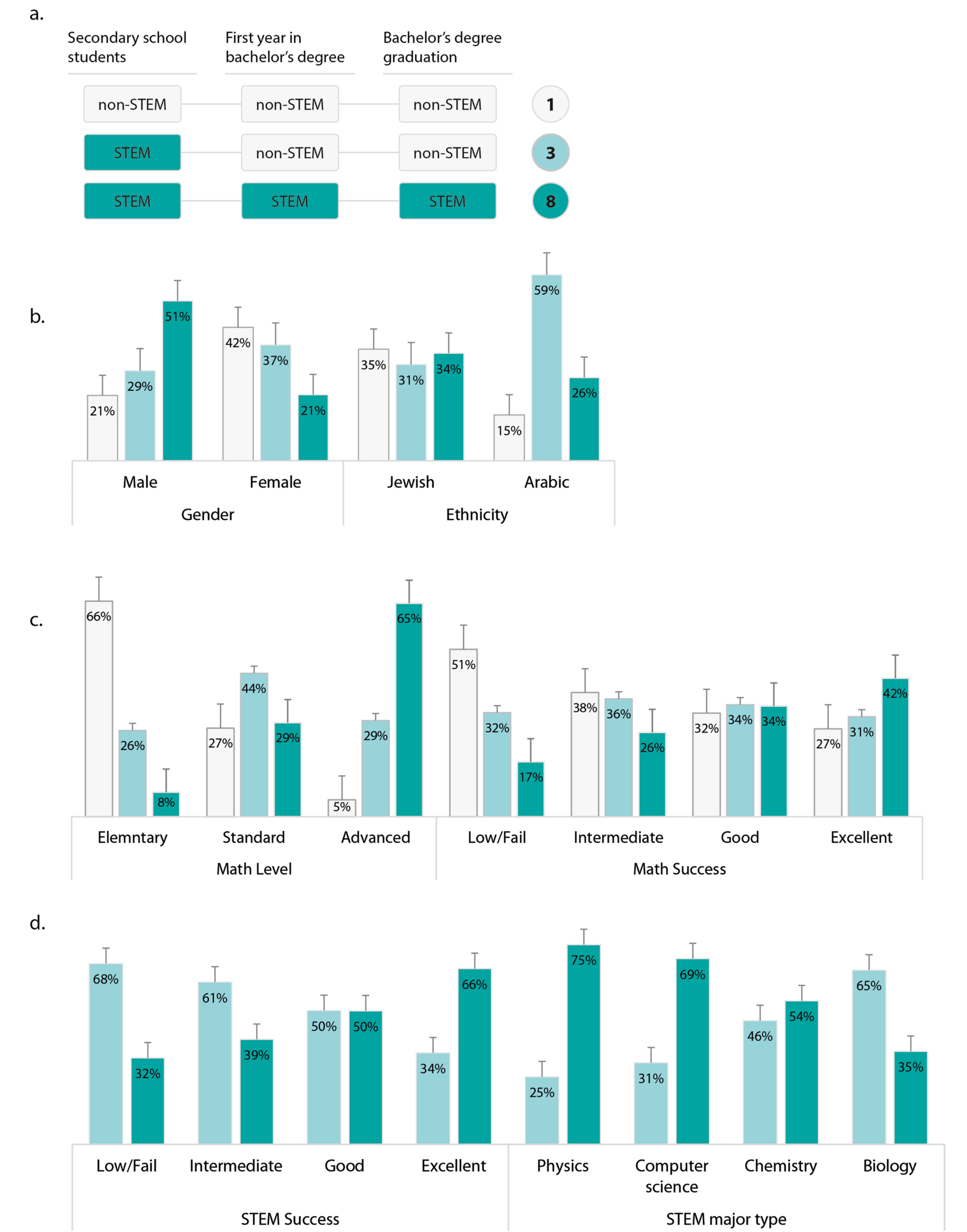

Fig. 7 (See legend on previous page.)

Table 3 The distribution of characteristics within secondary pathways beginning with a STEM secondary school major

Distribution within pathways		**Secondary pathways which began with STEM**	
		Pathway #4 STEM – STEM – non-STEM	**Pathway #6** STEM – non-STEM – STEM
Gender	Men vs. Women	The number of women is approx. 1.1 times more than men	The number of men is approx. 1.3 times more than women
Ethnicity	Jews vs. Arabs	There are approx. 2.3 times more Arab students then Jewish students	There are approx. 1.2 times more Jewish students than Arab students
Mathematics level	Advanced vs. Standard vs. Elementary	The number of advanced students is approx. 1.1 and 3.2 times more than standard and elementary students, respectively	The number of advanced students is approx. 1.5 and 4.2 times more than standard and elementary students, respectively
Mathematics success	Excellence vs. Good vs. Intermediate vs. Low/fail	The number of excellent students is approx. 1.2, 1.4, and 7.4 times more than good, intermediate, and Low/fail students, respectively	The number of excellent students is approx. 1.2, 1.5, and 6.8 times more than good, intermediate, and Low/fail students, respectively
Science major success	Excellence vs. Good vs. Intermediate vs. Low/fail	The number of good students is approx. 1.2 and 11.2 times more than intermediate and Low/fail students, respectively, and approx. 1.5 times more than excellent students	The number of good students is approx. 1.1 and 13.7 times more than intermediate and Low/fail students, respectively, and approx. 1.3 times more than excellent students

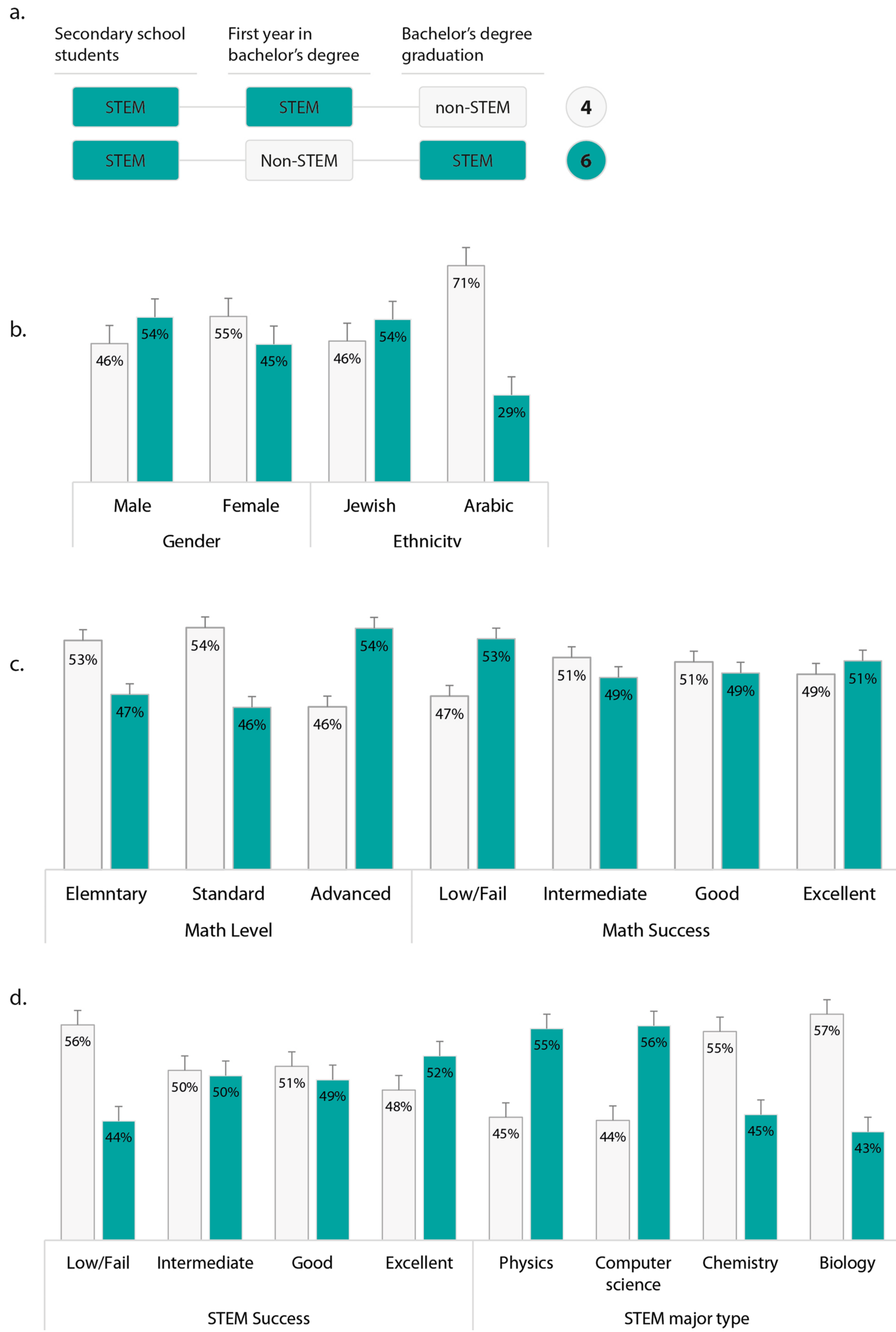

Fig. 8 The characteristics of the pathways begin with secondary STEM major: **a** illustration of the relevant pathways, #4 and #6; **b** the distribution of the demographic characteristics between these pathways; **c** the distribution of the educational characteristics in mathematics between these pathways; **d** the distribution of the educational characteristics in STEM major between these pathways

Table 4 Distribution of characteristics within secondary pathways which began with a non-STEM secondary major

Distribution within pathways		Secondary pathways which started with non-STEM		
		Pathway #2 non-STEM – STEM – non-STEM	**Pathway #5** non-STEM – non-STEM – STEM	**Pathway #7** non-STEM – STEM – STEM
Gender	Men vs. Women	The number of women is approx. 1.4 times more than men	The number of women is approx. 1.9 times more than men	The number of *men* is approx. 1.6 times more than women
Ethnicity	Jews vs. Arabs	There are 3.7 times more Jewish students as compared to Arab students	There are 2.5 times more Jewish students as compared to Arab students	The number of Jewish students is approx. 4.2 times more than Arab students
Mathematics level	Advanced vs. Standard vs. Elementary	The number of elementary students is approx. 1.5 and 5.4 times more than standard and advanced students, respectively	The number of elementary students is approx. 1.9 and 4.8 times more than standard and advanced students, respectively	The number of elementary students is approx. 1.2 and 3.1 times more than standard and advanced students, respectively
Mathematics success	Excellence vs. Good vs. Intermediate vs. Low/fail	The number of intermediate students is approx. 3.1 times more than Low/fail students, and approx. 1.1 and 1.3 times more than good and excellent students, respectively	The number of intermediate students is approx. 2.9 times more than Low/fail students, and approx. 1.2 times more than good and excellent students	The number of intermediate students is approx. 2.9 times more than Low/fail students, and approx. 1.1 times more than good and excellent students

compared to those who did not persist in STEM studies in higher education, i.e., learners in pathway #4.

Regarding the educational characteristics in mathematics (Fig. 8c), the findings are partly consistent with those found in relation to the differences revealed in the dominant pathways, as in pathway #6 there is a higher representation of learners who study advanced-level mathematics, as compared to path #4. That is, the mathematics level studied in secondary school, have an ongoing impact on the type of bachelor's degree studied.

According to the Kruskal–Wallis test, the distributions between pathways #4 and #6, by level of success in the matriculation exam in mathematics and in secondary STEM major, did not reach significant. Hence, these variables are not distinguishing characteristics for these pathways. These findings are in line with the findings from previous study (Kohen & Nitzan, 2022), which shows that mathematics level studied has a greater influence on future academic choices than math accomplishments. When comparing the type of secondary school STEM major for the secondary pathways, #4 and #6 (Fig. 8d), we discovered partially similar findings to those found for the two dominant pathways started with STEM in secondary school (see Fig. 7d). Considering the secondary pathways (#4 and #6), a statistically significant difference was found in the distribution by biology and computer science only. Students who study computer science are more likely to follow path #6, ending up with a STEM degree, whereas those who study biology are more likely to follow path #4, ending up with a non-STEM degree. It is consistent with previous research in the field, showing that physics and computer science studies are better predictors of further STEM studies and employment than biology studies (e.g., Card & Payne, 2017, 2021).

Distribution by secondary pathways which began with a non-STEM secondary major

Similar to the findings presented in previous sections, we present Table 4, describing the distribution within the three secondary pathways beginning with a non-STEM major in secondary school according to various demographic and educational characteristics of learners. We then display Fig. 9a which illustrates the relevant secondary pathways and serves as a legend for the charts that follow. Figure 9b and c illustrates the distribution *between* the three secondary pathways for each of the demographic and educational characteristics.

A Kruskal–Wallis test revealed significant differences between pathway #7 and pathways #2 and #5, the secondary pathways which start with a non-STEM secondary major, in the following characteristics only: gender and mathematics level studied. In addition, significant differences were found between pathways #2 and #7 with respect to mathematics level of success. Regarding the demographic variables (Fig. 9b), the findings are partly consistent with the above findings which described the dominant pathways with respect to gender differences, so those who showed more persistence toward STEM in higher education, i.e., students those related to pathway #7, are predominantly male, as compared to students who did not persist in STEM studies in higher education, i.e., those related to pathway #2. However, the distribution by gender in pathway #5 is the opposite of that mentioned above. Although this pathway ended with a STEM bachelor's degree, it includes a majority of women. It will, therefore, be interesting to examine what are the salient features of this pathway which are different from pathway #2, leading to the completion of a STEM bachelor's degree. According to the Kruskal–Wallis test, the distribution by ethnicity did not reach a significant level.

Regarding the educational characteristics in mathematics (Fig. 9c), the findings are partly consistent with those found in relation to the differences revealed in the dominant pathways. First, the distribution by mathematics success did not reach significant. Second, in pathway #7 there is a higher representation of learners who study advanced-level mathematics and excel in the matriculation exam in mathematics compared to pathway #2. These findings regarding pathways #2 and #7 are supported by previous research, which suggests that the best predictor of completion of a STEM bachelor's degree is studying advanced mathematics in secondary school (Kohen & Nitzan, 2022). However, interestingly, with respect to pathway #5, most students in this pathway study mathematics at the elementary level. That is, even though they study mathematics at the most basic level and are not exposed to STEM studies in secondary school, they eventually complete a bachelor's degree in STEM subjects.

Focusing on pathway #5, although it represents students which start with non-STEM studies in secondary school and in first year in undergraduate studies, students in this path finally graduate a STEM bachelors' degree, with mostly of women and learners who study mathematics at an elementary level. In spite of its uniqueness, pathway #5 represents the lowest proportion of undergraduates (1.2%), therefore cannot be generalized to the entire student population in terms of selection processes towered a bachelor's degree. We propose, however, to conduct further research to examine additional characteristics of this pathway, including type of undergraduate degree or success in the first year of academic study, in order to gain a deeper understanding regarding the unique characteristics of this path. For example, Stearns and colleagues (2020) revealed that students who succeed in non-STEM studies in the first year of undergraduate

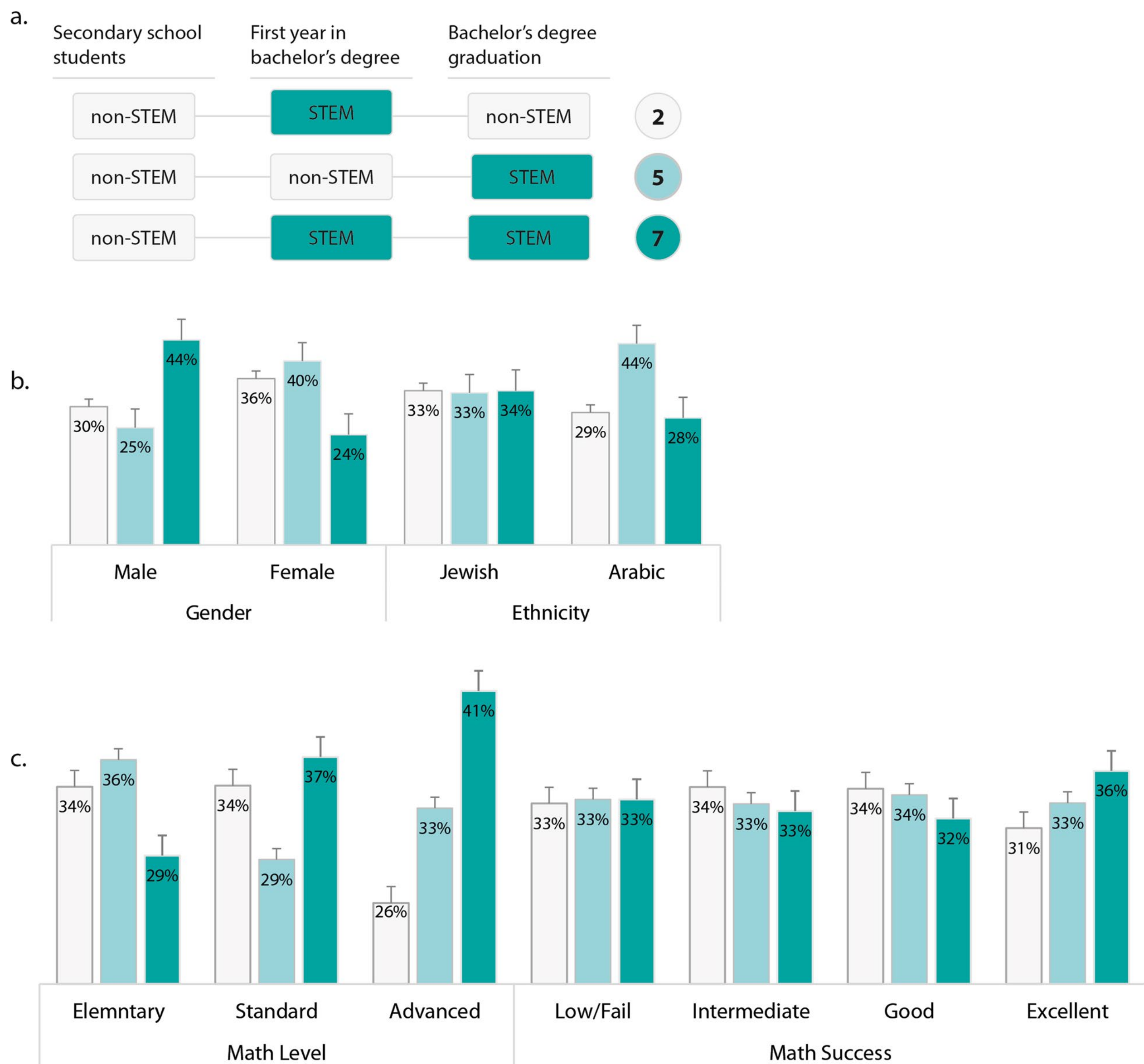

Fig. 9 The characteristics of the pathways begin with a non-STEM secondary major: **a** illustration of the relevant pathways, #2, #5, and #7; **b** the distribution of the demographic characteristics between these pathways; **c** the distribution of the educational characteristics in mathematics between these pathways

studies, might change their course of study to degree in biology.

Study limitations

The main limitation of the study lies in the nature of the data collected, which is based on objective behavioral data, e.g., choice of subject of study or level of success in mathematics. The main advantage of using this type of data was the affordance of big-data analysis that was based on 534,590 records retrieved from the Israeli CBS for several points in time over one and a half decades, and accordingly the affordance for investigating a long-term effect of secondary school studies on further important choice junctions in the path toward STEM career. On the other hand, the research literature emphasizes variety of variables that have a great influence on career choice, which can provide a broader and deeper picture about learners in the various pathways. For example, a research review by Reinhold and colleagues (2018) found that extracurricular STEM activities in or out of school were important predictors of choosing STEM for study and career. Another study, conducted by Stearns and colleagues (2020), using multimethod approach, revealed that academic performance, based on administrative records, is not the key factor that explains the gender gaps in STEM choice. Through analysis of interviews conducted with senior students, Stearns and colleagues indicated that especially among women, interests in STEM fields and beliefs in their ability to success in STEM, were influencing factor on the choice of majoring in STEM. Including both subjective and objective data might contribute to addressing the full SCCT framework (Lent & Brown, 2013). We thus recommend examining these variables and others, such as subjective attitudes variables, through in-depth interviews and attitudes questionnaires with reference to the segmentation of the sample according to the eight pathways proposed in the present study. Additional suggestion for further research refers to exploring the influence of both subjective and objective behavioral variables on various STEM fields, instead of capturing this dependent variable as a whole, as was done in this study for the goal of creating the three-tier tree.

Conclusions and study contribution

The present study explores the various pathways toward a STEM or non-STEM career, by tracking one's education choices across the lifespan, thus providing indications of the sustainability of secondary school's effect on future choice, as well as the interrelations between the various phases, through an extensive investigation of all possible pathways within these phases. For this purpose, and based on a big data analysis, this study presents a three-tier tree which recognizes eight pathways leading to a STEM or non-STEM bachelor's degree.

Our aim in this study was to get insight into the long-term effect of education choices made in secondary school and entrance into STEM professions, through the use of a large data sets retrieved from the CBS in Israel. Despite the relatively local nature of this study, the study reflects a challenge of STEM attrition documented widely in many countries (Leu, 2017; Miller, 2018; OECD, 2021; Staus et al., 2019). Moreover, as a technologically and economically developed country, Israel is comparable to many developed countries in the OECD (Jerrim et al., 2018), such as the United States, Germany, and Sweden (Zehavi & Breznitz, 2017). Specifically, the ethnic diversity in Israel is similar to other countries, like the United States (Degazon et al., 2015).

In reviewing the main characteristics discussed in this manuscript, e.g., mathematics and STEM studies, gender and ethnic minority gaps in choosing STEM in higher education, similarities as well as differences can be seen compared to other countries (Degazon et al., 2015; Marginson et al., 2013; OECD, 2021). For example, although mathematics is not a mandatory subject in secondary school in the United States, in other countries such as Finland, China, Taiwan, etc., the requirements for studying mathematics until the end of secondary school are similar to those in Israel (Marginson et al., 2013). Comparatively, Israel has a similar gender distribution to that observed in OECD countries when it comes to pursuing a course of study in higher education, with an emphasis on STEM subjects (Degazon et al., 2015; Friedman-Sokuler & Justman, 2016, 2020; Marginson et al., 2013). Therefore, observations based on the Israeli population can be generalized and the recommendations of this study can also be applied to other developed countries.

As such, this study contributes theoretically to broadening the conceptualization of various pathways toward pursuing a STEM career, based on the CSM model of Lent and Brown (2013). As the CSM provides a comprehensive overview of the main constructs that influence STEM career decision-making along with predictive variables (particularly demographic and educational), the current study relates these constructs to three main phases that correspond to key choice junctions throughout one's lifespan.

Accounting for all possible dropouts as well as movements between study fields during significant points in lifespan, the study presents a three-tier tree which highlights eight pathways leading to STEM or non-STEM bachelor's degrees (see Fig. 10).

Our findings point on three dominant pathways, reflecting the largest number of learners who had completed a bachelor's degree. As two of those pathways reflect a linear choice track, namely the STEM and non-STEM persistent learner (pathways #8 and #1, respectively), the most significant finding is the recognition of pathway #3, reflecting the biggest 'leak' from STEM in secondary school to non-STEM in higher education. With that, this study implies that the critical transition occurs between the choice goals and the choice actions phases (Lent & Brown, 2013). Figure 11 illustrates the 'leak' occurring in pathway #3, that is more pronounced at the transition toward undergraduate studies, than the transition made during undergraduate studies until graduation (Chen & Soldner, 2013; Miller, 2018; Witteveen & Attewell, 2020).

Additionally, although not reflecting the majority of the study sample, we revealed secondary pathways, some of which account for dropouts from STEM fields mostly

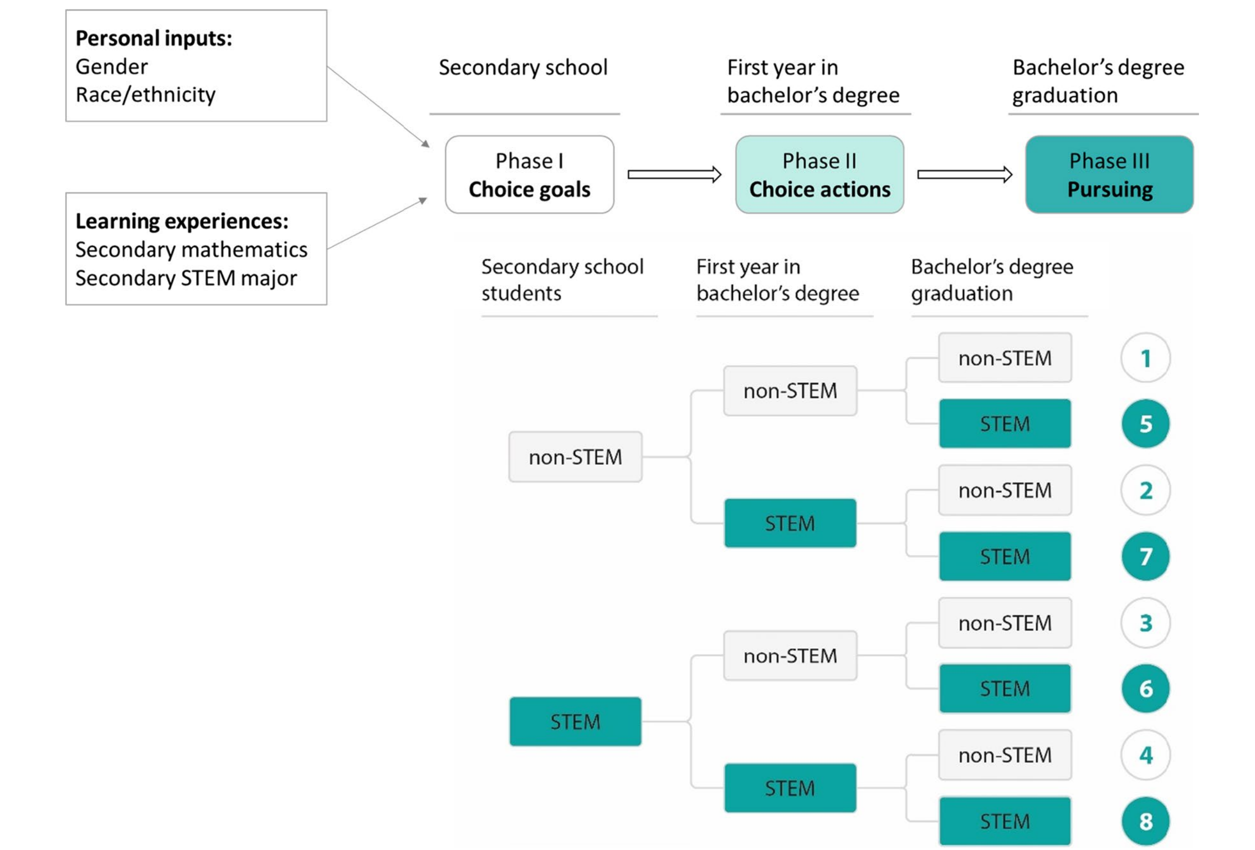

Fig. 10 The three-tier tree established in this study, and its interrelation to the CSM model (Lent & Brown, 2013)

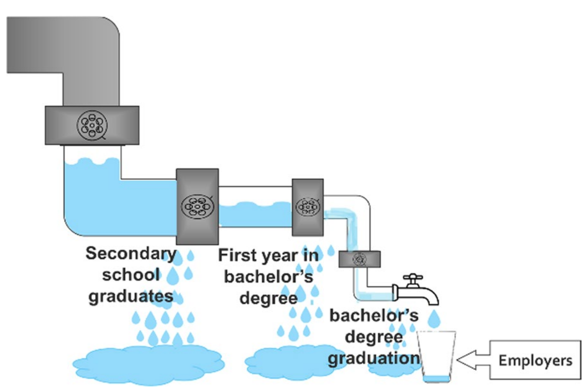

Fig. 11 Illustration of the leaking occurring in pathway #3 during significant periods in one's lifespan

reported in the literature, but others revealed the movement from non-STEM into STEM fields, either those which occurred in the transition to higher education or those which occurred during higher education studies, such as pathway #6 which reflects students who dropped out of the STEM field in their first year of bachelor's degree, then returning to the STEM field at their bachelor's degree graduation. With that, this study contributes to the research gap about STEM dropouts from secondary school to higher education, which display both linear or not linear directions from secondary STEM studies toward STEM or non-STEM graduation, as well as other directions that account for the opposite movement from non-STEM to STEM (Miller, 2018; Witteveen & Attewell, 2020).

The study further theoretically establishes the relationships between demographic and educational factors, and various pathways of STEM orientation. These factors are presented at the CSM by Lent and Brown (2013) as having an effect on learners' goals, actions and outcomes/attainments, which we consider in our study as important choice phases in lifespan. The study sheds some light on the characteristics of learners who persist in STEM studies after secondary school and those who drop out. Our research shows that secondary school mathematics, specifically the level of mathematics studied, and success in science majors, especially physics and computer science studies, have a significant impact on future STEM choices. We particularly point at a combination of characteristics in accordance with pathway #3 that do not encourage students to continue in STEM fields in higher education. Acknowledging the educational factors, we revealed that the most influencing factors that hinder students to persist in STEM professions, include non-advanced mathematics in secondary school, lack of excellence in mathematics and in a science major in secondary school, and studying biology as a major in secondary school. These findings accord with the CSM model, as self-efficacy expectations and outcome expectations are perceived as mediating variables between one's learning experiences and adaptive career behaviors across the career lifespan, which in turn may result in more positive outcomes.

The study's methodological contribution is in the creation of the three-tier tree which represents more deeply and extensively the three stages of choice throughout one's lifespan. Accordingly, our creation of the 'choice variable', which includes the eight values—each representing the various different pathways, allowed us to explore the relationships between the different pathways, while accounting for demographic and educational characteristics of learners in each pathway.

From a practical point of view, the study presents a longitudinal view that is based on big-data analysis, through the focus on three periods in lifespan that were found to be important choice junctions in the process of STEM career decision-making. As we provide an extensive view of all the various possible pathways, and the characteristics of learners in each pathway, our study first contributes to understanding the factors that affect the decline in STEM choice as a profession throughout lifespan. Second, the study points out that the solution to the STEM shortage should not be limited to 'fixing' the leaky pipeline, but must also consider alternative pathways in which students return to the STEM track after having 'leaked' to other subjects. According to Miller (2018), even a 5% increase in moves in the direction of STEM has the power to produce about 63,000 STEM graduates per year. From this practical view, we present recommendations for policy makers and other influencing factors in the educational system for encouraging STEM choice, particularly in higher education and the completion of a STEM bachelor's degree. First, to place greater focus on increasing the percentage of secondary school students studying physics and computer sciences as a major. Second, we recommend increasing the percentage of students who study advanced mathematics. Third is the importance of providing students in a secondary STEM major and during mathematics studies with an experience of academic success, which might influence their future STEM choice. As a complementary perspective, our identification of diverse pathways and characterization of learners in each path points to the weak spots which hinder a choice of the STEM professions, interfering with the exploration of new avenues through which the choice of STEM subjects can be preserved and expanded.

Appendix A

In this section, we present the distribution of demographic (Table 5) and educational (Table 6) characteristics according to the eight pathways, respectively. Based on these data, statistical analyses were performed to identify the differences in distribution of characteristics among the different pathways.

Table 5 The distribution of demographic characteristics according to the eight pathways

			Eight pathways								
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
Gender	Male	N	21,752	1,022	27,492	3,232	356	1,712	5,644	33,606	94,816
		% of gender	22.9%	1.1%	29.0%	3.4%	0.4%	1.8%	6.0%	35.4%	100%
	Female	N	62,232	1,466	49,596	3,672	664	1,364	3,626	19,526	142,146
		% of gender	43.8%	1.0%	34.9%	2.6%	0.5%	1.0%	2.6%	13.7%	100%
Ethnicity	Jewish	N	79,648	2,386	63,142	5,432	970	2,786	8,884	48,076	211,324
		% of ethnicity	37.7%	1.1%	29.9%	2.6%	0.5%	1.3%	4.2%	22.7%	100%
	Arabic	N	3,600	62	13,262	1,406	38	252	222	4,064	22,906
		% of ethnicity	15.7%	0.3%	57.9%	6.1%	0.2%	1.1%	1.0%	17.7%	100%

Table 6 The distribution of educational characteristics according to the eight pathways

			Eight pathways								
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
Math level (ML)	Advanced	N	4,086	230	21,500	3,030	120	1,574	1,372	33,300	65,212
		% of ML	6.3%	0.4%	33.0%	4.6%	0.2%	2.4%	2.1%	51.1%	100%
	Standard	N	22,468	894	33,490	2,848	310	1,080	3,530	15,358	79,978
		% of ML	28.1%	1.1%	41.9%	3.6%	0.4%	1.4%	4.4%	19.2%	100%
	Elementary	N	55,326	1,334	20,432	938	580	374	4,250	4,062	87,296
		% of ML	63.4%	1.5%	23.4%	1.1%	0.7%	0.4%	4.9%	4.7%	100%
Math success (MS)	Excellent	N	11,573	282	12,051	1,226	124	556	1,163	11,421	38,396
		% of MS	30.1%	0.7%	31.4%	3.2%	0.3%	1.4%	3.0%	29.7%	100%
	Good	N	11,174	331	11,106	1,052	136	454	1,130	7,485	32,868
		% of MS	34.0%	1.0%	33.8%	3.2%	0.4%	1.4%	3.4%	22.8%	100.0%
	Intermediate	N	12,849	371	11,224	857	149	363	1,286	5,472	32,571
		% of MS	39.4%	1.1%	34.5%	2.6%	0.5%	1.1%	3.9%	16.8%	100.0%
	Low/fail	N	4,820	121	2,743	165	51	81	449	993	9,423
		% of MS	51.2%	1.3%	29.1%	1.8%	0.5%	0.9%	4.8%	10.5%	100.0%
Science success (SS)	Excellent	N			7,025	865		415		9,120	17,425
		% of SS			40.3%	5.0%		2.4%		52.3%	100%
	Good	N			13,436	1,274		545		9,045	24,300
		% of SS			55.3%	5.2%		2.2%		37.2%	100%
	Intermediate	N			15,655	1,091		476		6,844	24,066
		% of SS			65.1%	4.5%		2.0%		28.4%	100%
	Low/fail	N			1,735	113		40		552	2,440
		% of SS			71.1%	4.6%		1.6%		22.6%	100%

As there is no information about science success for pathways that started in a non-STEM major in secondary school, these boxes are blank

Abbreviations

CBS: Central Bureau of Statistics; CSM: Career Self-Management; LPM: Leaky Pipeline Metaphor; SCCT: Social Cognitive Career Theory; SCT: Social Cognitive Theory; STEM: Science, Technology, Engineering and Mathematics.

Acknowledgements

Not applicable.

Author contributions

ONT drafted the manuscript and analyzed and interpreted the data retrieved from the Israeli Central Bureau of Statistics. ZK contributed with coding and analyzing the data as well as reviewed the drafts and contributed to the draft revisions. All authors read and approved the final manuscript.

Funding

Partial financing on behalf of: (a) Samuel Neaman Institute, Technion, Israel Institute of Technology, and (b) the National Institute for Testing and Evaluation (NITE) in Israel.

Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available due to their national confidentiality and are only available through the Israeli Central Bureau of Statistics.

Declarations

Competing interests

The authors declare that they have no competing interests.

Received: 2 March 2022 Accepted: 28 September 2022
Published online: 08 October 2022

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