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# Perceptions of STEM alumni and students on developing 21st century skills through methods of teaching and learning

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ABSTRACT

21st century skills are essential for career readiness. We investigated the development of students' 21st century skills at a science, technology, engineering, and mathematics (STEM) research university: Technion – Israel Institute of Technology. We designed a self-reporting questionnaire covering 14 skills and deployed it to approximately 1500 students and alumni. Respondents were asked to rate each skill based on the degree to which it was developed during their studies. Domain-general skills scored higher than STEM-specific skills or soft (interpersonal) skills, whereas STEM-specific skills scored higher than soft skills. Content analysis revealed nine methods of teaching and learning through which skills developed. The four active methods had a small effect on domain-general skills, while the five passive methods had a medium-to-large effect on these skills. Active methods had a medium-size effect on both STEM-specific and soft skills, whereas passive methods had no effect on either group. Our contribution lies in identifying and matching methods to skills.

## 1. Introduction

The current era is marked by an increasing need for a new set of skills, often named generic skills or 21st century skills. This need has been recognised by researchers (e.g., Bentur, Zonenshein, Nava, & Dayan, 2019; Marbach-Ad, Egan, & Thompson, 2016), educational bodies (e.g., ABET, 2019; National Research Council, 2013), and economic bodies (e.g., Ananiadou & Claro, 2009; World Economic Forum, 2016). However, fostering 21st century skills in undergraduate science, technology, engineering, and mathematics (STEM) students remains a challenge (Winberg et al., 2019), with STEM graduates at times underprepared for what present-day STEM professions require (Jang, 2016). Students' academic achievement levels rarely correspond to their respective levels of 21st century skills (Badcock, Pattison, & Harris, 2019). Therefore, changes to STEM curriculum and instruction in both high school and higher education are required to prepare students for the current economy (ABET, 2019; Birenbaum et al., 2006; National Research Council, 2013).

Technion – Israeli Institute of Technology, hereinafter referred to as the Institute, is a top-tier STEM higher education institute and research university that grants mostly STEM degrees, with approximately 15,000 enrolled students. As is the case with many other higher education institutes, the Institute's curricula and instruction modalities have been undergoing changes, with curricula having a larger component of interdisciplinary content, and instructional modalities involving more components of engagement.

The Technion's senior management has recognised the need to make changes to curricula in preparation for the needs of the 21st century, including an emphasis on new skills. This study, which is part of ongoing efforts at educational reform at the Institute, investigated the self-reported perceptions of Institute alumni and final-year students, both undergraduate and graduate, regarding 21st skill development. Previous studies in STEM higher education have investigated the relations between instructional and learning elements on the one hand and the development of 21st century skills on the other hand (Grace, Weaven, Bodey, Ross, & Weaven, 2012; Guo, 2018; Hodgson, Varsavsky, & Matthews, 2014; Kember & Leung, 2005; Tsang, 2018; Virtanen & Tynjälä, 2019). To the best of our knowledge, our study is the first to investigate this topic with a comprehensive population, comprising alumni and students, undergraduates and graduates, and every major discipline of STEM higher education. This study is also the first to present a classification of teaching and learning methods. The methods, derived via content analysis of participants' responses to the open-ended item, have been connected to the 21st century skill or skills which it

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helped develop.

## 2. Literature review

This section covers frameworks for 21st century skills and methods of teaching and learning which relate to the development of these skills. Prominent international and national organizations have published frameworks for 21st century skills concerning K-16 education. The Organization for Economic Co-Development—OECD (Ananiadou & Claro, 2009), the US National Research Council—National Research Council (2013), Next Generation Science Standards—NGSS Lead States (2013), and Partnership for 21st Century Skills—P21 (Trilling & Fadel, 2013) have all published their own frameworks. For higher education in particular, the Association of American Colleges and Universities (2007) and Accreditation Board for Engineering and Technology—ABET (2019) have both published their own frameworks for 21st century skills in education. This list shows that most of the frameworks did not focus exclusively on STEM higher education; indeed, 21st century skills are neither unique to higher education nor to the training of scientists and engineers.

Examining 21st century skills raises several questions: (1) What skills that the education system has struggled to instil in students continue to be essential and what skills have become irrelevant? (2) What new skills are becoming essential in the 21st century? (3) What are the transformations that are necessary for imparting the relevant skills that render them suitable for the 21st century needs?

Dede (2010) is a seminal study on 21st century skills. Focusing on questions concerning skills that have undergone change or on new skills, this research does not disqualify traditional skills; rather, the author claims these traditional skills should be re-examined to decide which has remained relevant and what adjustments are required for responding to 21st century educational requirements. A prominent example for this re-examination concerns tasks which are carried out by people, as compared to those carried out by machines. This division of tasks between people and machines is constantly shifting as information and communication technology continually expands the ability of machines to perform tasks that humans were previously required for carrying out (Levy & Murnane, 2004).

van Laar, van Deursen, van Dijk, and De Haan (2017) provided a framework of 21st century digital skills for professionals that features conceptual dimensions and key operational components. Based on a systematic academic literature review, in which they screened about 1600 articles, they found 75 which met a predefined set of criteria, from which they identified seven core skills and five contextual skills with focus on digital technologies. Chu, Reynolds, Tavares, Notari, and Lee (2017), who attempted to identify similarities across different 21st skill frameworks, placed overlapping or identical concepts together, providing users and readers with a deeper understanding of what these frameworks convey. The comparison included P21, Ananiadou and Claro (2009), and Assessment and Teaching of Twenty-first Century Skills (Griffin & Care, 2015), which vary across international contexts but nevertheless share commonalities. Highlighting the P21 framework, Chu et al. (2017) suggested using it as an anchor for comparing and juxtaposing skill dimensions as learning goals developed and disseminated in various international contexts.

Of particular interest for our study are the frameworks published by ABET (2019), National Research Council (2013) and NGSS Lead States (2013). ABET's *Student outcomes* (2019) are defined as "…what students are expected to know and be able to do by the time of graduation. These relate to the skills, knowledge and behaviours that students develop as they progress through the program" (ABET, 2019, criterion 3. student outcomes). The US National Research Council (NRC) Committee on Defining Deeper Learning and 21st Century Skills refers to 21st century skills as "… important dimensions of human competence … [which] society [now] desire[s] that all students attain a level of mastery … previously unnecessary for individual success in education and the workplace." (National Research Council, 2013, sum-2). The NRC has identified three domains of competence associated with 21st century skills: cognitive, intrapersonal, and interpersonal, as well as areas with strongest overlap between 21st century skills and discipline-based standards in science and engineering. It is this area of overlap which we are concerned with in this study, since it pertains specifically to science and engineering, and focuses on higher education. The Next Generation Science Standards (NGSS Lead States, 2013) were formulated by the US National Research Council for k-12 science education. These standards are split into (a) disciplinary core ideas, (b) crosscutting concepts, and pertinent to the present study – (c) science and engineering practices.

Finally, while not strictly a framework, *critically important 21st century skills for STEM disciplines* (Jang, 2016) are skills that were reported by 9950 professionals who hold STEM jobs registered in a US Department of Labor database as most important for their respective roles. We chose this list for our study as it was conceived based on empirical data, and as such it is relevant to the skills students should be developing during their higher education studies.

Based on the frameworks and literature we surveyed, we found that critical thinking, problem solving, collaboration, creativity, and communication have a high degree of consensus. As noted, these skills related to secondary and tertiary education in general, not to STEM education in particular. Since the present study focuses on Technion alumni and students, we chose frameworks particular to 21st century skills in science and engineering: ABET's *student outcomes* (2019), Next Generation Science Standards (NGSS Lead States, 2013) *science and engineering practices* (2013), NRC (2013) 21st century skills for science and engineering, and *critically importantskills for STEM disciplines* from the US Labor Department database (Jang, 2016).

### 2.1. Methods of teaching and learning

Educational methods may or may not involve an instructor, which is why we opted for the term *methods of teaching and learning* to describe various methods in which students participate while studying in higher education. Another useful distinction can be made between passive and active learning methods, where the latter can be defined by having students (1) engage in learning activities, (2) reflect on those activities or use higher-order thinking, and (3) work in groups (Dori & Belcher, 2005; Freeman et al., 2014; Prince, 2004). Studies in STEM education have found that active learning methods, focused on interaction and/or authentic problems provide opportunities for expressing or developing 21st century skills (e.g., Crebert, Bates, Bell, Patrick, & Cragnolini, 2004; Dori & Belcher, 2005; Dori, Dangur, Avargil, & Peskin, 2014; Freeman et al., 2014; Hodgson et al., 2014; Holmes, Wieman, & Bonn, 2015; Kember & Leung, 2005; Mintz & Tal, 2018; Ogilvie, 2009; Talmi, Hazzan, & Katz, 2018; Tsang, 2018; Virtanen & Tynjälä, 2019).

Virtanen and Tynjälä (2019) conducted a detailed investigation into the pedagogical practices involved in the development of generic (21st century) skills within undergraduate students of chemistry, teacher education, and physical education. They categorized these skills into three groups: (a) creativity and innovation skills, (b) critical thinking, complex problem-solving, and decision-making skills, and (c) learning to learn or metacognition. They also categorized teaching practices into four groups: (a) forms of teaching and learning, (b) features of a constructivist learning environment, (c) features of an integrative learning environment, and (d) features of course atmosphere. Like Virtanen and Tynjälä (2019), our study also investigated 21st century skills and their development through teaching methods. However, unlike Virtanen and Tynjälä (2019), who investigated chemistry education exclusively, we investigated STEM education. In our study, we focused on a variety of methods of teaching and learning in STEM higher education. We provide herein an approach for identifying methods of teaching and learning and match them to the 21st century skills they had developed, without pre-determining the methods themselves.

**Table 1**
Study participants.

| Demographic Variable | | Alumni | | Students | | All |
|---|---|---|---|---|---|---|
| | | N | % | N | % | N = 1578 |
| Gender | Men | 648 | 61 | 412 | 39 | 1060 |
| | Women | 282 | 54 | 236 | 46 | 518 |
| Language | First | 796 | 59 | 554 | 41 | 1350 |
| | Other | 133 | 58 | 95 | 42 | 228 |
| Degree from Institute | Undergraduate only | 511 | 60 | 342 | 40 | 853 |
| | Graduate only | 71 | 41 | 102 | 59 | 173 |
| | Undergraduate and Graduate | 347 | 63 | 205 | 37 | 552 |

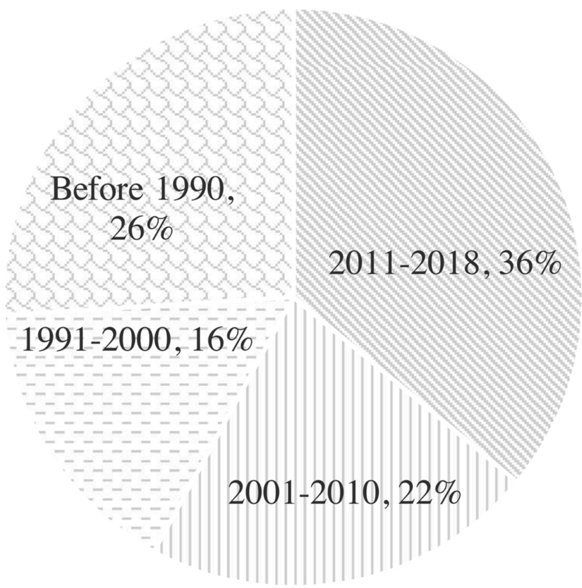


**Fig. 1.** Bachelor's Degree graduation period of respondents.

## 3. Materials and methods

We conducted the study under a mixed-methods methodology, including both quantitative and qualitative elements. We used statistical analyses to compare close-ended item data and content analysis (Creswell, Shope, Plano Clark, & Green, 2006) to identify categories with open-ended item data. The study received the approval of the Technion's Ethics in Research Committee.

### 3.1. Participants

This study included 1578 participants: 930 alumni and 648 fin. l-year students. As Table 1 shows, participants were represented across genders and first languages. Every faculty in the Technion was represented in the study sample. Participants who were final-year students comprised 15% of undergraduate students and 32% of the entire final-year graduate student cohort at the Institute.

As Fig. 1 shows, participants represented a broad range of Bachelor's degree graduation periods, indicating a broad age range. Almost three-fourths (74%) of the study participants completed their undergraduate degree within the current century, and more than a third (36%) obtained their undergraduate degree in the current decade.

The study sample included participants from every faculty in the Technion: Engineering faculties comprised 86.3% of the alumni participants and 89.6% of the student participants, in science faculties alumni and students were13.7% and 10.4%, respectively, and in other faculties—7.1% and 2.3%, respectively.

### 3.2. Online questionnaire

We developed an online questionnaire to assess the perceptions of alumni and final-year students regarding the development of their own 21st century skills. We selected 14 such skills for inclusion in the questionnaire. The list of skills was taken from frameworks that pertained to STEM education or STEM-related industry (see 'Literature Review' and Appendix A above). We selected 11 skills that appeared in at least two of those frameworks, specifically items that were described as either skills (National Research Council, 2013), practices (NGSS Lead States, 2013) or outcomes (ABET, 2019). As the same, or similar, skills might have a different name depending on the framework in question, we considered skills with similar descriptions as the same skill and gave it the most appropriate and concise name we could find. For example: "an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors" (ABET, 2019, criterion 3.2), and *systems thinking* (National Research Council, 2013), were all named *systems thinking*.

Based on guidance from Technion senior management, we added to the list three more skills. These were included in one of the frameworks or elevated from being subskills: (1) *entrepreneurship*, since our country is known as a global leader in entrepreneurship (Senor & Singer, 2011); (2) *question posing*, since this skill is fundamental in science education (Barak & Rafaeli, 2004; Kohen, Herscovitz, & Dori, 2020); (3) *intercultural communication,* because the country the Institute is in is an immigration country of numerous cultural groups.

The final list of 14 skills is as follows: complex problem-solving; creativity; critical thinking; collaboration; engineering design; experimenting and testing; individual learning; intercultural communication; STEM knowledge application in a professional environment; oral communication; question posing; systems thinking; and written communication. See Appendix A for details.

Since there was no option to assess a large sample of alumni and students externally for each skill, we opted for self-reporting of skill development. According to Volkwein, Luttaca, Harper, and Domingo (2007), the reliability of self-reporting among students is high when taken in aggregate, i.e., in large groups, exhibiting moderate-to-high positive correlation. Previous studies on students' 21st century skills have made use of self-reporting as the sole indicator of skill development (e.g., Hodgson et al., 2014; Kember & Leung, 2005; Tsang, 2018; Virtanen & Tynjälä, 2019).

We designed an initial version of the questionnaire in Google Form and deployed it to five senior faculty members and five graduate students. Based on the initial respondents' answers to questionnaire items concerning 21st century skills, STEM education experts validated that respondents' understanding of each skill was sufficiently accurate. Based on feedback received on these initial questionnaires, we developed the final version of the questionnaire. Aside from question concerning personal variables of gender, first language, period of graduation for Bachelor's degree (if relevant), and the current degree being studied at the Institute (if relevant), the questionnaire contained two key questions: (1) close-ended item – participants were requested to score each skill from 1 to 5 (Likert scale) according to the degree that skill developed during their studies at the Institute; (2) open-ended item – participants were requested to select one skill which they scored 4 or 5 (high or very high level of development, respectively) and provide a free text description of how this skill developed. The limitation imposed on the second question ensured that respondents would describe only those skills that they had developed to at least a high level.

### 3.3. Data analysis

We conducted several analyses of the collected data, all using SPSS 26. 21st century skill development levels were investigated using Exploratory Factor Analysis (EFA) and t-tests. The internal consistency (reliability) of the factors we identified via the EFA was evaluated by calculating Cronbach's Alpha for each factor. We also performed content analysis on responses that participants provided for the open-ended item concerning skill development. Next, to examine whether any associations existed between 21st century skills and the identified methods of teaching and learning, we conducted a 13 by 9 Chi-Square test of association at 95% confidence level. This test did not include the skill of intercultural communication, since no respondent noted it in the open-ended item. Lastly, to ascertain the contribution of active methods of teaching and learning to reported skill development, we carried out a Cramer's V tests of effect size for the methods we identified as active (from active learning), and for the methods we identified as passive.

To explore if and how skills divided into distinct groups based on commonalities between said skills, we conducted EFA based on respondents' reported level of skill development for each of the 13 skills. Based on the assumption that factors will be independent from one another, representing independent skill groups, we carried out EFA with orthogonal rotation (varimax). We used a threshold of .500 for factor loading, which together with the large sample size ensured the statistical meaningfulness of the EFA results (Yong & Pearce, 2013). We ascertained the internal consistency of the item scores (skill scores) within each factor by calculating Cronbach's Alpha for each factor, and when each item within that factor was removed.

We then compared reported levels of skill development as follows:

(1) Between the skill groups identified via EFA,
(2) between participants who received only an undergraduate degree from the Institute and those who received a graduate degree from the Institute (with or without an undergraduate degree), and
(3) between final-year undergraduate and graduate students at the Institute.

The first analysis was carried out via repeated measures ANOVA, being a within-subject comparison of multiple dependent variables without including independent variables, while the latter two analyses were carried out via two-tailed t-tests for independent samples. All three analyses were carried out at a 95% confidence level. The null hypothesis for all three comparisons was that no difference existed in skill scores, while the alternative hypothesis was that differences did exist.

We also performed content analysis on responses that participants provided for the open-ended item concerning skill development. We did this based on approach of Braun and Clarke (2006), from initial coding through to defined themes. We used 'bottom-up', inductive semantic coding to ascertain themes in responses to the open-ended item concerning skill development. Content analysis began with initial semantic coding conducted separately by two of the co-authors on 100 randomly selected responses – 50 of alumni and 50 of students. This coding was reviewed by all three authors of this paper, leading to a revised coding scheme agreed upon by all three authors, with clearly defined themes. Using the revised scheme, the same two co-authors as before coded 100 other responses, also of 50 alumni and 50 respondents, which were randomly selected from those response that had not been coded during the initial round of coding. Interrater agreement on this categorization came to $r = .836$ (Pearson correlation). Using the revised coding scheme, one of the authors of this study coded the remaining data of responses.

Next, to examine whether any association existed between 21st century skill and the methods of teaching and learning through which participants reported these skills had developed during their studies, we conducted a 13 by 9 Chi-Square test of association at 95% confidence level. The null hypothesis was that there was no association between methods of teaching and learning and the scores respondents gave to skills, while the alternative hypothesis was that such an association existed.

**Table 2**
Factor loadings for participants' perceptions of developing 21st century skills during their studies at the institute.

| 21$^{st}$ century skill ($N = 1475$[1]) | Factor I | Factor II | Factor III[2] |
|---|---|---|---|
| Individual learning | .768 | | |
| Complex problem-solving | .743 | | |
| Critical thinking | .673 | | |
| Question posing | .598 | .522 | |
| Oral communication | | .829 | |
| Written communication | | .769 | |
| Intercultural communication | | .693 | |
| Collaboration | | .645 | |
| Entrepreneurship | | .531 | |
| Creativity | | .512 | |
| Engineering design | | | .845 |
| Systems thinking | | | .627 |
| Experimenting and testing | | | .551 |
| STEM knowledge application | | | .523 |

[1] Some participants scored only some of the skills and left others blank due to their major (e.g., students who majored in science disciplines did not score the engineering design skill).
[2] Factor analysis was constrained a threshold of .500 (absolute value). Rotation converged in six iterations.

Lastly, to ascertain the contribution of active methods of teaching and learning to reported skill development, we applied the criteria of active learning as described under sub-section 'Methods of teaching and learning' to the nine methods we identified and ascertained which of them should be classified as active methods, and which should be classified as passive methods. We then carried out Cramer's V tests of effect size for (a) the methods we identified as belonging to active learning as one group, (b) the methods we identified as belonging to passive learning as one group, and (c) for each group of skills we identified via the EFA.

## 4. Results

In this section, we present the results of our data analysis: identifying distinct groups of 21st century skills within our list of 14 skills, comparing reported levels of 21st century skill development, identifying themes for how these skills had developed according to respondents, and ascertaining which methods contributed most strongly to skill development during respondents' time at the Institute.

### 4.1. Identifying distinct groups of 21st century skills

Participants answered 14 close-ended items, scoring each skill between 1 and 5, based on their perceived development of skills during their studies at the Institute. To explore whether scores were divided into specific groups of skills, we conducted exploratory factor analysis (EFA) on these scores without any constraint on the number of factors. The analysis showed that three factors explained 59.9% of the total variance in scores, two factors explained 52.1%, and one factor explained 42.5%. Table 2 shows the factor loadings obtained for each

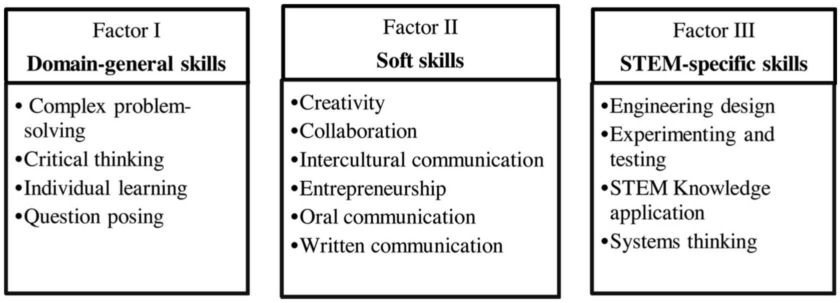


**Fig. 2.** 21st century skills grouped into factors derived via exploratory factor analysis.

**Table 3**
Cronbach's Alpha for groups of 21st century skills.

| Skill group Cronbach's Alpha = .892 ($N$ = 1475) 14 skills | Skill | Cronbach's Alpha with item removed |
|---|---|---|
| Domain-general skills Cronbach's Alpha = .784 (N = 1531) Four skills | Complex problem-solving | .725 |
| | Critical thinking | .680 |
| | Individual learning | .785 |
| | Question posing | .712 |
| Soft skills Cronbach's Alpha = .844 (N = 1506) Six skills | Creativity | .824 |
| | Collaboration | .821 |
| | Entrepreneurship | .823 |
| | Intercultural communication | .824 |
| | Oral communication | .803 |
| | Written communication | .815 |
| STEM-specific skills Cronbach's Alpha = .720 (N = 1513) Four skills | Engineering design | .667 |
| | Experimenting and testing | .653 |
| | STEM knowledge application | .696 |
| | Systems thinking | .614 |

**Table 4**
Alumnus respondents' perceptions of developing their 21st century skills.

| 21st century skill | With only an undergraduate degree from the Institute (N = 504–514) | | With a graduate degree from the Institute (N = 387–397) | | t-value |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | |
| Individual learning | 4.61 | .63 | 4.56 | .74 | −1.109 |
| Complex problem-solving | 4.43 | .72 | 4.42 | .76 | −.236 |
| Critical thinking | 4.04 | .94 | 4.01 | 1.05 | −.436 |
| STEM knowledge application | 3.90 | 1.00 | 4.03 | 1.03 | 1.920 |
| Question posing | 3.86 | .99 | 3.85 | 1.05 | −.103 |
| **Engineering design** | 3.83 | 1.11 | 3.56 | 1.27 | **−3.438*** |
| Systems thinking | 3.75 | 1.05 | 3.70 | 1.19 | .730 |
| **Experimenting and testing** | 3.66 | 1.04 | 3.82 | 1.12 | **2.227*** |
| Creativity | 3.49 | 1.10 | 3.61 | 1.11 | 1.613 |
| Collaboration | 3.19 | 1.14 | 3.22 | 1.21 | .371 |
| Entrepreneurship | 3.10 | 1.14 | 3.18 | 1.22 | .922 |
| **Written communication** | 3.01 | 1.10 | 3.41 | 1.17 | **5.227*** |
| **Oral communication** | 2.93 | 1.10 | 3.26 | 1.17 | **4.270*** |
| Intercultural communication | 2.72 | 1.12 | 2.80 | 1.20 | .983 |

Skills with significant differences are in bold.
* $p < .05$.

**Table 5**
Student respondents' perceptions of developing their 21st century skills.

| 21st century skill | Undergraduate students (N = 248–256) | | Graduate students (N = 228–241) | | t-value |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | |
| **Individual learning** | 4.65 | .68 | 4.52 | .85 | **−2.140*** |
| Complex problem-solving | 4.28 | .88 | 4.18 | .96 | 1.388 |
| Critical thinking | 3.80 | 1.13 | 3.93 | 1.09 | 1.499 |
| STEM knowledge application | 3.60 | 1.07 | 3.64 | 1.17 | .498 |
| Question posing | 3.60 | 1.10 | 3.71 | 1.14 | 1.250 |
| **Engineering design** | 3.64 | 1.16 | 3.07 | 1.36 | **−5.619*** |
| Systems thinking | 3.43 | 1.18 | 3.34 | 1.23 | .966 |
| **Experimenting and testing** | 3.32 | 1.21 | 3.53 | 1.27 | **2.179*** |
| **Creativity** | 3.19 | 1.17 | 3.50 | 1.17 | **3.286*** |
| Collaboration | 2.98 | 1.17 | 3.04 | 1.27 | .526 |
| **Entrepreneurship** | 2.75 | 1.11 | 3.07 | 1.18 | **3.535*** |
| **Written communication** | 2.90 | 1.25 | 3.37 | 1.25 | **4.681*** |
| **Oral communication** | 2.82 | 1.22 | 3.26 | 1.24 | **4.441*** |
| Intercultural communication | 2.78 | 1.21 | 2.89 | 1.27 | 1.087 |

Skills with significant differences are in bold.
* $p < .05$.

skill.

Based on the distribution of factor loadings shown in Table 2, we named each factor as a group of skills, as shown in Fig. 2. All three factors had satisfactory convergent validity, with each variable having a factor loading large than .500. Factor III had satisfactory discriminant validity, with each variable loading only on that factor. The variable *question posing* cross-loads on Factors I and II – more so on Factor I than on Factor II. Apart from this variable, these factors also had satisfactory construct validity. For purposes of further analysis, we attributed this variable to Factor I, as it loaded more highly on this factor.

Next, we calculated Cronbach's Alpha within each skill group. Table 3 shows that each skill group had good internal consistency (> .7), and that removing an item did not lower the overall Cronbach's Alpha score of any skill group, with one exception: removing 'individual learning' from 'domain-general skills' changed Cronbach's Alpha for that skill group from .784 to .785. We left this variable for further analysis as it did not load on any other factor in the EFA, and since the difference between the two Cronbach's Alpha values is minute (~ .1%).

### 4.2. *Comparing reported levels of skill development*

Conducting repeated measures ANOVA to compare the three skill groups ($N$ = 1552), we found that the three groups were significantly different from each other ($F$ = 1671.054, $p$ < .05). Bonferroni tests between skill groups yielded significant differences ($p$ < .05) between (a)

**Table 6**
Example statements by respondents about methods of teaching and learning.

| Responder code | 21st century skill being referred to | Method of teaching and learning | Responder statement |
|---|---|---|---|
| S494371 | Individual learning | Course assignment | The homework exercises are at a very high level which requires a lot of individual learning |
| S66078 | Complex problem-solving | Delving into material | To solve problems, one needs to search for a lot of information in various information sources while being helped by academic staff. |
| S61237 | Individual learning | Exam preparation | One cannot always learn all the course during the lectures and recitations, and many times you need to study a course completely on your own before an exam. |
| S46720 | Experimenting and testing | Laboratory lesson | The laboratories I did during my degree were very clear and helped me learn how to plan experiments on my own. |
| A63401 | Critical thinking | Lecture | During the lectures, various explanations were given and it was made clear how to make decisions when various opinions exist. |
| A11144 | Collaboration | Project | The projects and courses at the Technion require going beyond the domain of the degree and there is a relation to many other domains. |
| A34861 | Creativity | Recitation | Courses at the Technion emphasize solving novel problems that students did not encounter beforehand. |
| S74524 | Creativity | Research | During the research degree, one runs into problems requiring creative and innovative thinking. |
| A70727 | Individual learning | Revision of course material | I found that I am not assimilating information during lectures and cannot retain the information; so, I studied for most of my degree from my own or other people's written summaries, and from text books. |

[1]A is alumni, S is student.

domain-general skills ($M = 4.17$, $SD = .72$) and soft skills ($M = 3.11$, $SD = .90$), (b) domain-general skills and STEM-specific skills ($M = 3.65$, $SD = .86$), and (c) soft skills and STEM-specific skills.

We carried out two-tailed independent-sample t-tests with 95% confidence level, comparing the skill development of undergraduate alumni to graduate alumni. We carried out the same tests for final-year students. As Tables 4 and 5 show, the skills which graduates found to be

**Table 7**
Cramer's V test results for active and passive methods of teaching and learning.

| Skills included in test | Active methods | | | Passive methods | | |
|---|---|---|---|---|---|---|
| | N | Cramer's V | p | N | Cramer's V | p |
| All 13 skills | 365 | .486 | $< .05$ | 462 | .574 | $< .05$ |
| Domain-general skills[1] | 148 | .227 | $< .05$ | 428 | .633 | $< .05$ |
| Soft skills[2] | 108 | .423 | $< .05$ | 6 | .500 | n.s. |
| STEM-specific skills[3] | 109 | .469 | $< .05$ | 28 | .243 | n.s. |

[1] Complex problem-solving, critical thinking, individual learning, and question posing.
[2] Creativity, entrepreneurship, collaboration, oral communication, and written communication.
[3] Engineering design, experimenting and testing, STEM knowledge application, and systems thinking.

**Table 8**
Examples of participants' responses regarding teaching and learning methods.

| Respondent code | 21[st] century skill being referred to | Method of teaching and learning | Form of teaching and learning | Respondent statement |
|---|---|---|---|---|
| S47484 | Collaboration | Project | Working with others | *[Working on a] project with three or even six other people, teaches [one] a lot about patience, tolerance of others, coping with oneself and with others.* |
| A86547 | Written communication | Course assignment | Writing | *[My] oral communication progressed to a large degree during my doctoral studies, because there were many papers to write.* |
| S66078 | Experimenting and testing | Research | Direction from instructor | *Experimenting and testingas part of Master's Degree research – the instructor gave a lot of autonomy in directing the research and advised [us] especially during critical junctures.* |
| A39055 | Written communication | Laboratory lesson | Writing | *[My] Written communication improved through papers and reports I was tasked to write.* |

| 21st Century Skills (N = 827) | Methods of teaching and learning | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Revision of course material (34%) | Course assignment (17%) | Project (12%) | Delving into material (10%) | Research (10%) | Lecture (5%) | Exam preparation (4%) | Laboratory lesson (4%) | Recitation (3%) |
| Individual learning (53%) | 64% | 9% | 2% | 17% | 3% | | 6% | | |
| Complex problem-solving (10%) | | 39% | 18% | 5% | 6% | 1% | 8% | 5% | 19% |
| Experimenting and testing (7%) | | | 5% | | 50% | 2% | | 42% | |
| Critical thinking (5%) | | 26% | 5% | | 29% | 26% | 5% | 5% | 3% |
| Engineering design (4%) | | 16% | 56% | | | 25% | | 3% | |
| Collaboration (4%) | | 47% | 47% | | 3% | | | 3% | |
| Creativity (3%) | | 46% | 29% | | 4% | 4% | 8% | 4% | 4% |
| STEM Knowledge application (3%) | | 17% | 25% | 4% | 17% | 29% | | 4% | 4% |
| Oral communication (3%) | | 61% | 22% | | 13% | 4% | | | |
| Systems thinking (3%) | | 5% | 19% | | 24% | 43% | | 5% | 5% |
| Entrepreneurship (2%) | | | 94% | | | 6% | | | |
| Question posing (2%) | 13% | 19% | 6% | | 19% | 31% | | | 13% |
| Written communication (2%) | | 46% | | | 54% | | | | |

**Fig. 3.** Heat map of 21st century skills and the methods of teaching learning through which these skills developed.
***Note***. Percentages are rounded to the nearest whole number. Charcoal: larger than 45%; dark grey: 30–44%; grey: 15–29%; cloudy grey: 1–14%; blank: smaller than 1%.

significantly more developed than undergraduates, for both alumni and students, were *experimenting and testing*, *oral communication*, and *written communication*. The skills we found to be more developed by graduates than by undergraduates, but only for final-year students, were *creativity* and *entrepreneurship*. Finally, the skills we found to be more developed by undergraduates then by graduates were *engineering design* for both alumni and students and *individual learning* for final-year students.

### *4.3. Identifying themes through which skills were developed by respondents*

Our final coding scheme categorized each response to the open-ended item concerning skill development into one of nine methods of teaching and learning. Since both graduates and students did not indicate the intercultural communication in their responses to the open-ended item, we excluded this skill from analysis of the open-ended item.

Table 6 contains example statements from participants that describe each method.

A 13 by 9 Chi-Square test of association between 13 skills and nine methods of teaching and learning revealed that the association between these variables was significant, $X^2$ (96, N = 827) = 1324.969, p < .05.

### *4.4. Ascertaining the contribution of the active learning methods to skill development*

We classified four of our nine methods as active methods, as they fulfilled all three criteria. These were *project*, *course assignment*, *research*, and *laboratory lesson*.

We then investigated the contribution of these methods to respondents' reported skill development and compared it to that of the five other, passive methods, using Cramer's V tests at 95% confidence level. As Table 7 shows, we found that active and passive methods both had similarly medium-sized effects on reported skill levels. When testing only for domain-general skills, both types of method also had an effect on reported skill levels, but this time, active methods had a small effect size, while passive methods had a medium-to-large effect size. Conversely, when testing only for soft skills and only for STEM-specific skills, we found that active methods had a medium-sized effect on both skill groups, and that passive methods had no effect at all on either group of skills.

Table 8 provides further elucidation for the connections between methods of teaching and learning, and forms of teaching and learning, by presenting quotes from participants' responses to the open-ended item.

Finally, to describe in detail the relations between methods and skills, we created a heat map, shown in Fig. 3. The percentages within the heat map show the proportion of participants who chose to answer how a specific skill had developed through a specific method. The percentages for each skill, i.e., in each row, sum up to 100%. For example, 64% (*N* = 437) of participants who chose to elaborate on the development of *individual learning*, described *revision of course material* as the method through which they developed this skill. As Fig. 3 shows, three of the four methods which we classified as active lead (descriptively) the list of methods in the number of skills they develop: *project* with 12 of 13 skills, and both *course assignment* and *research* with 11 skills each. The skill developed by the largest number of methods—all except for *revision of course material*—is *complex problem-solving*, while the two skills which developed by the least number of methods—only two methods each (not the same two)—are *entrepreneurship* and *written communication*.

## 5. Discussion

Educational and economic organizations and researchers have recognised an increasing need for 21st century skills (ABET, 2019; Ananiadou & Claro, 2009; Marbach-Ad et al., 2016; National Research Council, 2013; van Laar et al., 2017; World Economic Forum, 2016); however, developing 21st century skills in undergraduate and graduate STEM students can be challenging (Jang, 2016; Winberg et al., 2019). Active learning methods are particularly useful for developing 21st century skills, and especially soft skills (Crebert et al., 2004; Freeman et al., 2014; Hodgson et al., 2014; Holmes et al., 2015; Kember & Leung, 2005; Mintz & Tal, 2018; Ogilvie, 2009; Talmi et al., 2018; Tsang, 2018; Virtanen & Tynjälä, 2019). The methods of active teaching and learning discussed in this paper can be related to the 'forms of teaching and learning' by Virtanen and Tynjälä (2019).

The objectives of our study were to characterise participants' development of 21st century skills during their studies and to describe how participants developed those skills during their studies. To achieve

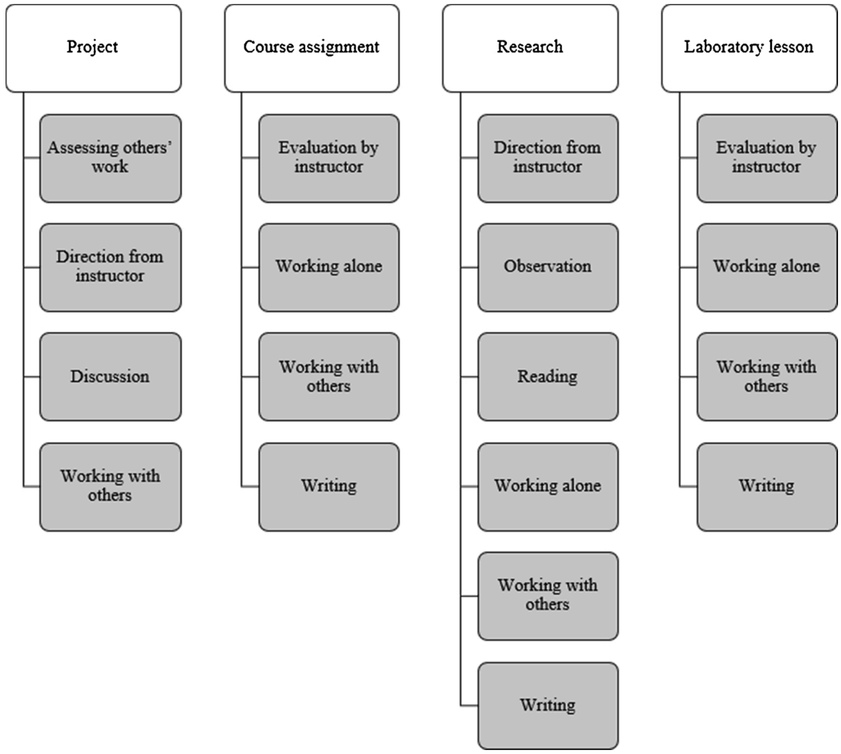


**Fig. 4.** Active methods of teaching and learning (white rounded rectangles) and their constituent forms of teaching and learning (grey rounded rectangles). ***Note***. Superordinate: active methods of teaching and learning, subordinates: forms of teaching and learning taken from Virtanen and Tynjälä (2018).

the first objective, we discuss our findings regarding (a) skill groups and (b) comparisons between undergraduates and graduates. For the second objective, we first discuss our findings regarding methods of teaching and learning through which 21st century skills had developed. Next, we compare those methods we identified as active with the forms of teaching and learning in Virtanen and Tynjälä (2019). We then provide recommendations for policy makers and researchers, based on our study findings and outline ongoing initiatives at the Institute for developing students' 21st century skills. Finally, we discuss the limitations of and contribution of our study.

### 5.1. Groups of 21st century skills

Using exploratory factor analysis, we classified 21st century skills into three groups: domain-general skills, soft skills, and STEM-specific skills (see Table 4 and Fig. 2). We found that domain-general thinking skills outscored STEM-specific skills, which in turn outscored soft skills. Interestingly, two skills had very similar factor loadings on Factor I (domain-general skills) and on Factor II (soft skills): *creativity* (.496 and .512, respectively) and *question posing* (.598 and .522, respectively).

Fig. 3 shows that 79% of responses pertaining to the development of creativity mentioned three methods—*course assignment*, *project*, and *laboratory lesson*—all involving social interaction. This can explain why creativity, even though often considered in education as a domain-general skill (Ananiadou & Claro, 2009; National Research Council, 2013), had a similar factor loading on the group of soft skills. This duality was also expressed in statements made by participants in their responses to the open-ended item concerning skill development. Some participants described *creativity* as a skill they developed on their own: "During a research degree, one encounters problems that require creative and innovative thinking." (S74524); "Many courses in computer science require creativity. There are many solutions for each question, and one needs to think and plan how to solve it efficiently." (S47834). Other participants described creativity as a skill they had developed through social activity: "At times, projects require creativity, when you need to look for new directions." (S89941); "Creativity … developed through competition with other students for a high-quality solution." (A11144).

Some participants described *question posing* as a skill they had developed on their own: "At the Technion, I learnt to ask questions, not to be satisfied with the answer I receive, investigate myself, and ask more questions." (A4958); "My research pushes me to ask questions … about my findings." (S47593). Other participants described *question posing* as a skill they had developed through social activity: "Teamwork … required … structured question posing." (A66690); "Question posing … [is] necessary … for those practicing medicine. Most of the lecturers pushed us to ask … express an opinion that is not trivial" (A50068550). Previous studies have also referred to *question posing* as a thinking skill which manifests via interaction with an instructor or peers, thus having both cognitive and social (interpersonal) components (Dori & Herscovitz, 1999; Herscovitz, Kaberman, Saar, & Dori, 2012; Zohar & Dori, 2003).

### 5.2. Comparing reported levels of 21st century skill development

Graduate alumni and graduate students scored significantly higher for some of the investigated skills—especially soft skills—compared with undergraduate alumni and undergraduate students, respectively (see Tables 5 and 6). We can explain this finding by the higher prevalence of projects and research in graduate curricula when compared with undergraduate curricula, as well as by the larger number of opportunities to present one's work in conferences, which arise during graduate studies and is almost absent in undergraduate studies. Previous studies conducted at the Institute have also shown that active learning methods are conducive to the expression or development of soft skills.

### 5.3. Identifying themes through which skills were developed by respondents

We found an association between reported levels of skill development and methods of teaching and learning; specifically, we found that active methods affected the development of soft skills and STEM-specific skills, while passive methods did not. As Fig. 4 shows, each method we identified can be said to comprise multiple forms of teaching and learning. The four active methods we identified all share one, and only one, form of teaching and learning: *working with others*. This form corresponds to 'working in groups' as an attribute of active learning (Dori & Belcher, 2005; Freeman et al., 2014; Prince, 2004). Indeed, it could be argued that more so than any other criterion, group work/working with others is the hallmark of active learning.

Interestingly, *course assignment* and *laboratory lesson* both mapped to the same forms of teaching and learning—*evaluation by instructor*, *working alone, working with others*, and *writing*—and not to any other forms; this may hint at the two methods being similar enough to be considered one and the same. It could be argued that these two methods are similar enough to be considered part of the same category of teaching and learning method.

### 5.4. Recommendations

For policy makers, we recommend courses and programs that include the active learning methods shown in our study which develop the often-neglected soft skills. Such courses and programs have been implemented at the Institute in recent years; however, these initiatives are still isolated, rather than integrated across the various curricula. They are also limited in scope rather than comprehensive, with traditional courses and programs still comprising most of the instruction at the Institute. We suggest developing and adopting a strategy for integrating those methods into undergraduate and graduate curricula in a comprehensive manner. Such integration would require not just revision of curricula, but investment in facilities and professional training for instructors. Winberg et al. (2019) listed interdisciplinary collaboration among the factors leading to development of pedagogical competence by STEM instructors in higher education, raising the need to include active learning in instructors' professional development. Special investment is required in undergraduate studies, for which both alumni and students reported they had developed soft skills the least.

For researchers, we recommend implementing the tool developed in this study in other STEM higher education institutes. This would enable these institutes to identify the perceived skill development level of their students and the methods which develop those skills the most.

Other promising avenues of research involve in-depth interviews with participants who responded to our questionnaire, wherein we would investigate further how their skills were developed during their studies, as well as the causes for the significant differences shown in Tables 5 and 6 between those participants who obtained an undergraduate degree from the Institute and those who did not.

In view of our recommendations, we note with optimism that several initiatives aimed at developed students' 21st century skills through active learning are already taking place at the Institute. These include an undergraduate semester-long course in which students study the course material at their own pace and time as participants in an edX MOOC, while small teams of students exercise their systems thinking by constructing complex conceptual models of technological systems, and in another version of this course engage in peer assessment of those conceptual models (Wengrowicz, Dori, & Dori, 2017). Another initiative is an annual technology entrepreneurship competition open to every student at the Institute, in which student teams compete in generating technological solutions to authentic problems, formulating a business plan, and pitching their ideas to investors. A further initiative is an annual technology entrepreneurship competition which is open to every student in the Institute. In this event, student teams compete in generating technological solutions to authentic problems as well formulating a business plan and pitching their ideas to investors.

### 5.5. Study limitations

The present study mostly focused on data collected through the online questionnaire, with some data provided from interviews with senior faculty members. Future research could make use of more interviews, as well as focus groups. In addition, due to regulatory reasons, we could not approach potential participants directly, but instead had to go through the offices of faculties at the Institute, as well as the alumni organisation. However, since we received responses from graduates and students of every faculty at the Institute and from various graduation periods, questionnaire participants did represent a comprehensive distribution of alumni and students. Another research limitation is the fact that the intercultural communication scored the lowest and responded did not relate to this skill in the open-ended item. This should be further investigated in a future study. Lastly, our study did not investigate comparisons between those who studied for the same degrees in the Institute and outside of it. Such an investigation could be conducted by deployed the questionnaire and interviewing participants at higher education institutes other than the one involved in the present study.

### 5.6. Study contributions

This study makes theoretical, methodological, and practical contributions. From the theoretical perspective, this research contributes to the body of knowledge of STEM higher education by bridging the literature gap on the development of 21st century skills through methods of teaching and learning. Our study is unique in that it provides a detailed account of how alumni and final-year students, both undergraduates and graduates, in a wide range of degrees in STEM higher education perceive how various methods of teaching and learning had developed their 21st century skills. Data collection via open-ended and close-ended items provided both quantitative and qualitative information. Another uniqueness is that the list of methods was derived through content analysis, rather than being predetermined. We made another theoretical contribution by identifying the four leading methods that develop most of the 21st century skills—*Project*, *course assignment*, *research*, and *laboratory lesson*.

Our methodological contribution, which applies to educators and researchers alike, lies in our approach for identifying the methods through which students' 21st century skills had developed and matching those methods to skills they had helped develop. As a practical contribution, this tool, which allowed us to identify the four most effective methods (see Fig. 4), can be applied by policy makers and instructors in other STEM higher education institutes. In these institutes, the methodology and tool can foster and improve students' preparedness for the 21st century.

## Declaration of Competing Interest

The authors have no conflict of interest to declare.

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## Appendix A

Table A1.

**Table A1**
Frameworks for 21st century skills used in developing the questionnaire.

| 21$^{st}$ Century Skill in Questionnaire | 21$^{st}$ student learning outcomes (ABET, 2019) | 21$^{st}$ century skills for science and engineering (NRC, 2013) | Science and Engineering Practices (NGSS Lead States, 2013) | Critically important skills for STEM disciplines (Jang, 2016) |
|---|---|---|---|---|
| Complex problem-solving | 3.1 An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics | | Asking Questions and Defining Problems | Complex problem solving |
| Creativity | Definitions: Engineering Design<br>"Engineering design is a process of devising a system, component, or process to meet desired needs and specifications within constraints. It is an iterative, creative, decision-making process…"<br>3.2 An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors | Adaptability<br>Non-routine problem solving | | |
| Critical thinking | | Critical thinking | Engaging in Argument from Evidence | Critical thinking |
| Engineering design | 3.2 An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors | | Constructing Explanations and Designing Solutions | |
| Experimenting and testing | 3.6 An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions | Planning and carrying out investigations | Analyzing and Interpreting Data<br>Planning and Carrying Out Investigations | Science |
| Entrepreneurship | | | | |
| STEM Knowledge application (in a professional environment) | 3.7 An ability to acquire and apply new knowledge as needed, using appropriate learning strategies | Using Mathematics and Computational Thinking | | Monitoring<br>Time management |
| Individual learning | 3.7 An ability to acquire and apply new knowledge as needed, using appropriate learning strategies | Self-development | | Active learning<br>Learning strategies |
| Intercultural communication | 3.3 An ability to communicate effectively with a range of audiences | | | |
| Collaboration | 3.5 An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives | Collaboration/ Teamwork | | Coordination<br>Social perceptiveness |
| Oral communication | 3.3 An ability to communicate effectively with a range of audiences | | Obtaining, Evaluating, and Communicating | Speaking |
| Question posing | | | Asking Questions and Defining Problems | |
| Systems thinking | 3.2 An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors | System thinking | Developing and Using Models | Systems analysis<br>Systems evaluation |
| Written communication | 3.3 An ability to communicate effectively with a range of audiences | Critical reading<br>Disciplinary discourse | Obtaining, Evaluating, and Communicating Information | Reading comprehension<br>Writing |

## References


ABET. (2019). *General criterion 3. Student outcomes from criteria for Accrediting Engineering Programs, 2018–2019*. Retrieved from https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2019-2020/#GC3.

Ananiadou, K., & Claro, M. (2009). *21st century skills and competences for new millennium learners in OECD countries*. Paris: Head of Publication Service, OECD.

Association of American Colleges and Universities. (2007). *College learning for the new global century: A report from the National Leadership Council for Liberal Education & America's Promise*. Assn of Amer Colleges.

Badcock, P. B. T., Pattison, P. E., & Harris, K.-L. (2019). Developing generic skills through university study: A study of arts, science and engineering in Australia. *Higher Education, 60*(4), 441–458.

Barak, M., & Rafaeli, S. (2004). On-line question-posing and peer-assessment as means for web-based knowledge sharing in learning. *International Journal of Human-computer Studies, 61*(1), 84–103.

Bentur, A., Zonnenshain, A., Nave, R., & Dayan, T. (2019). *Education of engineers in the 21st century: Paradigms, insights and implications to Israel*. Haifa, Israel: Samuel Neaman Institute for National Policy Research.

Birenbaum, M., Breuer, K., Cascallar, E., Dochy, F., Dori, Y., Ridgway, J., Wiesemes, R., & Nickmans, G. (2006). A learning integrated assessment system. *Educational Research Review, 1*(1), 61–67.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101.

Chu, S. K. W., Reynolds, R. B., Tavares, N. J., Notari, M., & Lee, C. W. Y. (2017). Twenty-first century skills and global education roadmaps. *21st century skills development through inquiry-based learning* (pp. 17–32). Singapore: Springer.

Crebert, G., Bates, M., Bell, B., Patrick, C.-J., & Cragnolini, V. (2004). Developing generic skills at university, during work placement and in employment: Graduates' perceptions. *Higher Education Research & Development, 23*(2), 147–165.

Creswell, J. W., Shope, R., Plano Clark, V. L., & Green, D. O. (2006). How interpretive qualitative research extends mixed methods research. *Research in the Schools, 13*(1), 1–11.

Dede, C. (2010). Comparing frameworks for "21st century skills", 20. *21st century skills: Rethinking how students learn* (pp. 51–76).

Dori, Y. J., & Belcher, J. (2005). How does technology-enabled active learning affect undergraduate students' understanding of electromagnetism concepts? *The Journal of the Learning Sciences, 14*(2), 243–279.

Dori, Y. J., & Herscovitz, O. (1999). Question-posing capability as an alternative evaluation method: Analysis of an environmental case study. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 36*(4), 411–430.

Dori, Y. J., Dangur, V., Avargil, S., & Peskin, U. (2014). Assessing advanced high school and undergraduate students' thinking skills: The chemistry—from the nanoscale to microelectronics module. *Journal of Chemical Education, 91*(9), 1306–1317.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., et al. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences, 111*(23), 8410–8415.

Grace, D., Weaven, S., Bodey, K., Ross, M., & Weaven, K. (2012). Putting student evaluations into perspective: The course experience quality and satisfaction model (CEQS). *Studies in Educational Evaluation, 38*(2), 35–43.

Griffin, P., & Care, E. (2015). *Assessment and teaching of 21st century skills: Methods and approach*. Springer: Dordrecht.

Guo, J. (2018). Building bridges to student learning: Perceptions of the learning environment, engagement, and learning outcomes among Chinese undergraduates. *Studies in Educational Evaluation, 59*, 195–208.
Herscovitz, O., Kaberman, Z., Saar, L., & Dori, Y. J. (2012). The relationship between metacognition and the ability to pose questions in chemical education. *Metacognition in science education* (pp. 165–195). Dordrecht, The Netherlands: Springer.
Hodgson, Y., Varsavsky, C., & Matthews, K. E. (2014). Assessment and teaching of science skills: Whole of programme perceptions of graduating students. *Assessment and Evaluation in Higher Education, 39*(5), 515–530.
Holmes, N. G., Wieman, C. E., & Bonn, D. A. (2015). Teaching critical thinking. *Proceedings of the National Academy of Sciences, 112*(36), 11199–11204.
Jang, H. (2016). Identifying 21$^{st}$ century STEM competencies using workplace data. *Journal of Science Education and Technology, 25*(2), 284–301.
Kember, D., & Leung, D. Y. P. (2005). The influence of active learning experiences on the development of graduate capabilities. *Studies in Higher Education, 30*(2), 155–170.
Kohen, Z., Herscovitz, O., & Dori, Y. J. (2020). How to promote chemical literacy? On-line question posing and communicating with scientists. *Chemistry Education Research and Practice, 21*(1), 250–266.
Levy, F., & Murnane, R. J. (2004). Education and the changing job market. *Educational Leadership, 62*(2), 80.
Marbach-Ad, G., Egan, L. C., & Thompson, K. V. (2016). Concluding thoughts. In G. Marbach-Ad, L. C. Egan, & K. V. Thompson (Eds.), *A discipline-based teaching and learning center* (pp. 223–226). Cham: Springer.
Mintz, K., & Tal, T. (2018). The place of content and pedagogy in shaping sustainability learning outcomes in higher education. *Environmental Education Research, 24*(2), 207–229.
National Research Council. (2013). *Education for life and work: Developing transferable knowledge and skills in the 21$^{st}$ century*. Washington, DC: National Academies Press.
NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: National Academies Press.
Ogilvie, C. A. (2009). Changes in students' problem-solving strategies in a course that includes context-rich, multifaceted problems. *Physical Review Special Topics-Physics Education Research, 5*(2), Article 020102.
Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education, 93*(3), 223–231.
Senor, D., & Singer, S. (2011). *Start-up nation: The story of Israel's economic miracle*. Random House Digital, Inc.
Talmi, I., Hazzan, O., & Katz, R. (2018). Intrinsic motivation and 21$^{st}$-century skills in an undergraduate engineering project: The formula student project. *Higher Education Studies, 8*(4), 46–58.
Trilling, B., & Fadel, C. (2013). *21$^{st}$ century skills: Learning for life in our times*. San Francisco, CA: Jossey-Bass.
Tsang, A. (2018). Positive effects of a programme on oral presentation skills: High-and low-proficient learners' self-evaluations and perspectives. *Assessment and Evaluation in Higher Education, 43*(5), 760–771.
van Laar, E., van Deursen, A. J., van Dijk, J. A., & De Haan, J. (2017). The relation between 21$^{st}$ century skills and digital skills: A systematic literature review. *Computers in Human Behavior, 72*, 577–588.
Virtanen, A., & Tynjälä, P. (2019). Factors explaining the learning of generic skills: A study of university students' experiences. *Teaching in Higher Education, 24*(7), 880–894.
Volkwein, J. F., Luttaca, L. R., Harper, B. J., & Domingo, R. J. (2007). Measuring the impact of professional education on student experiences and learning outcomes. *Research in Higher Education, 48*(2), 251–282.
Wengrowicz, N., Dori, Y. J., & Dori, D. (2017). Meta-assessment in a project-based systems engineering course. *Assessment & Evaluation in Higher Education, 42*(4), 607–624.
Winberg, C., Adendorff, H., Bozalek, V., Conana, H., Pallitt, N., Wolff, K., et al. (2019). Learning to teach STEM disciplines in higher education: A critical review of the literature. *Teaching in Higher Education, 24*(8), 930–947.
World Economic Forum. (2016). The future of jobs: Employment, skills and workforce strategy for the fourth industrial revolution. *Global challenge insight report, world economic forum*. Geneva. 2016.
Yong, A. G., & Pearce, S. (2013). A beginner's guide to factor analysis: Focusing on exploratory factor analysis. *Tutorials in Quantitative Methods for Psychology, 9*(2), 79–94.
Zohar, A., & Dori, Y. J. (2003). Higher order thinking skills and low-achieving students: Are they mutually exclusive? *The Journal of the Learning Sciences, 12*(2), 145–181.

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