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The New Engineering Education Transformation Program at Massachusetts Institute of Technology: The Evolving Design and Implementation of a Programmatic Evaluation Study

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Abstract. The New Engineering Education Transformation (NEET) program was launched in 2017 as a cross-departmental endeavor to reimagine undergraduate engineering education at Massachusetts Institute of Technology (MIT). NEET prepares students to tackle authentic 21st-century challenges by learning about new machines and systems, engaging in making and discovering activities, employing hands-on pedagogy, and cultivating the NEET Ways of Thinking. Students join the program for three years, from sophomore to senior year, in one of four threads: Autonomous Machines, Climate and Sustainability Systems, Digital Cities, or Living Machines. Once they complete the program, students receive a certificate of program completion. During Fall 2019, at the start of its third operational year, NEET leadership decided to initiate a comprehensive evaluation of the program. The authors conducted semesterial evaluations of the program from Spring 2020 till the present. Data for these evaluations were collected from program leadership, faculty, instructors, staff, and students, as well from institutional sources. We describe the evolving cycles of programmatic evaluation, including the design and implementation of these efforts, the suggestions made to program leadership, and the implementation and subsequent evaluation of those suggestions. We outline the challenges and opportunities which came up during evaluation. Finally, we provide recommendations for evaluators of similar programs.

Keywords. Engineering education, undergraduate education, programmatic evaluation.

Introduction

Present-day engineers are constantly called upon to provide solutions to mounting complex global challenges such as climate change, water and food scarcities, pandemics a rapidly expanding population with longer life expectancies, increasing migration and displacement, and looming threats of terrorism and nuclear deployment [1–2]. The need to tackle grand challenges has long initiated a call for reforms in

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engineering education that will arm future generations of engineers with the skills and the sophistication to become highly innovative global leaders, ready to deliver in both domestic and international settings [3–4].

Within this context, tackling such complex global challenges requires holistic educational approaches that combine multidisciplinary knowledge and updated multidisciplinary teaching and research methodologies. This demand for more holistic aproaches should be reflected in present-day engineering curricula and in the instructional way engineers of the future are formally trained. Even though the idea of approaching engineering education through a multi-disciplinary lens is not new to the academic community, most schools offer such opportunities to students mainly through scattered standalone multidisciplinary activities or classroom projects. As faculty and students are becoming increasingly familiar with these practices, some institutions have recognized that it is time to move to state-of-the-art multidisciplinary programs, labs, centers, and even schools [5]. The development, however, of multidisciplinary engineering programs neccessiates the development of new ways to perform programmatic evaluation.

In addition to multdisciplinarity, students need to acquire non-technical '21st century skills' and competencies such as communication, collaboration, creativity, and critical and ethical thinking. The need for students to acquire 21st century skills has been highlighted by multiple institutions such as the US National Research Council (NRC) [6], the World Economic Forum [7], and the Organization for Economic Co-Development (OECD) [8], or the ABET [9]. Many of these skills and competencies were historically aproached through schools traditionally belonging to the Humanities, Arts and Social Sciences (HASS), so an optimum way on how to bridge this gap and how to address such topics within the context of *science, technology, engineering, and mathematics* (STEM), although extremely important, has yet to be fully explored [5].

For a higher education institution to be able to deliver the sort of education described above to its students, it must develop strategies for action based on a clearly defined vision [10]. To proper guide this endeavor a benchmarking study was commissioned by MIT in 2016 [11]. Goal of this study was to explore what was at that point perceived as the state-of-the-art in undergraduate engineering education at a global level. In alignment with prior discussions, the study further highlighted the need for providing students with greater opportunities to practice engineering while working on authentic real world problems, while on the same time developing 21st century skills. This study ultimately led to the creation of the New Engineering Education Transformation (NEET) program in Fall 2017.

The following part of this paper is divided into three sections, starting with (1) an overview of the NEET program, followed by (2) a presentation and explanation of the design and implementation of our programmatic evalution model, and ending with (3) reflections on aforementioned programmatic evaluation efforts and authors recommendations for evaluators of similar programs.

1. The New Engineering Education Transformation Program

The NEET program[2] was launched as a pilot program in 2017, as an answers to MIT's efforts to reimagine undergraduate engineering education. An extra-curricular, cross-departmental endeavor with a focus on integrative, project-centric learning, the program aims to cultivate the essential skills, knowledge, attributes and qualities engineers of the future will need, to address the formidable challenges posed by the 21st century. The NEET program was conceived and developed based on four core principles:

1. Student education should focus on *preparation for developing new technologies*;
2. Student education should prepare them to become *makers and discoverers*, with engineering fundamentals applicable to both research and in practical careers;
3. Student education should be constructed around *the way students learn best* and must be both effective and engaging for the current era; and
4. Student education should empower them *to think more effectively and learn more effectively by themselves*.

These principles are realized through the program curriculum and pedagogy in the following ways:

- Students in each thread learn how to assemble, operate, design, and test new technologies.
- Students engage in interdisciplinary R&D in cross-departmental teams, inlcuding hands-on project work, applying state-of-the-art methods and technologies.
- Thread instructors apply a variety of pedagogical approaches and instructional tools, and students from different departments/majors work with and learn from each other by collaborating on scientific research and engineering design projects.
- The 12 'NEET Ways of Thinking'[3], which are approaches for addressing complex problems and which help students become better problems-solvers. These include, but are not limited to, *learning how to learn* (self-directed learning), *critical thinking and metacognition*, and *systems thinking*, to name a few.

Students join the program in their sophomore year in addition to their regular studies. In the usual four years they earn a degree in their chosen major and a NEET Certificate in one of four interdisciplinary 'threads': Autonomous Machines, Living Machines (both founding threads), Digital Cities, and Climate and Sustainability Systems (CSS). The latter thread was created in Fall 2021 as a merging of two previous

[2] https://neet.mit.edu/

[3] The NEET Ways of Thinking are detailed toward the bottom of this webpage: https://neet.mit.edu/about

threads—Advanced Materials Machines and Renewable Energy Machines. Program threads were conceived through collaboration of program leadership with volunteer faculty. For more information about the creation of the NEET CSS thread, see [12]. Previous developments in the program have been detailed elsewhere [13–16], including the effect of emergency (remote) teaching on the program curriculum and pedagogy [17].

Unlike most undergraduate STEM programs at MIT and elsewhere, the NEET program is both multi-year and cross-departmental, allowing students to collaborate together on interdiscilpinary projects of increasing complexity. These two features of NEET help students acquire considerable technical and human skills [18] in their chosen thread's domain. To verify this claim, program leadership has tasked the authors with designing and conducting a study on the career readiness of program alumni. This study is planned to take place over the academic year, 2022-2023.

As of Fall 2021, there were 232 students across sophomore, junior and senior years who had registered for the program. The program is voluntary and does not fulfill any requirements toward an engineering degree as prescribed by the University.

The NEET program team is comprised of (a) program leadership—an executive director and two faculty co-directors, (c) faculty thread leads—one or two members of faculty who oversee the direction of each NEET thread, (b) thread instructors—one instructor in each thread, (c) an engineering education expert, who is also one of the co-authors of this paper, (d) an academic administrator, and (e) and administrative asssistant.

2. Evaluating the New Engineering Education Transformation Program: Spring 2020–Fall 2021

In Fall 2019, NEET leadership established a collaboration with the MIT Open Learning (OL) Office to plan for the programmatic evaluation of NEET. Due to the nascent stage of the NEET program, and in alignment with OL's aim towards evidence-based educational development guided by Science of Learning findings, NEET and OL agreed that the process should not only include one summative evaluation study, but the team should conduct a series of recurring studies and treat upcomming findings as formative feedback meant to further guide program development through its first years. The team also treated this collaborations as an opportunity to further build MIT's know-how regarding evaluating educational innovation.

This initial effort at programmatic evaluation of NEET was meant for a) supporting the institute and the NEET program to in developing and deploying evaluation tools and instruments, b) carrying out a series of recurring studies to provide consistent feedback and suggestions to NEET leadership as the program evolves through its five-year pilot stage, and c) conducting a summative evaluation of the implementation of NEET's four guiding principles, as well as other aspects chosen by program leadership. Program success was measured based on (a) degree of adherence of curriculum and instruction to the program's guiding principles, (b) student enrollment in the program, and (c) student satisfaction with the program in both academic and experiential terms. Best practices for academic programmatic evaluation were followed according to MIT's report on institutional self-study [19] and Teaching and Learning Lab online resource on research and evaluation [20], as well as other relevant, established resources [21-23].

The evaluators, i.e., the people who carry out the programmatic evaluations of NEET, are the authors of this paper. Both have a PhD in engineering education, with the first author's field of expertise including 21st century skills and curriculum as well as the fostering and assessment of thinking skills, while the second author's field of expertise is in engineering curricula development, faculty training, and development and evaluation of national and international engineering programs and schools. The first author is NEET's engineering educational expert, while the second author is also an engineering education expert as well as a research scientist in OL, and does not have a permanent role in the NEET program.

In this section, we outline the background and process of evaluating the NEET program from Spring 2000–Fall 2021. We begin by describing the first, pilot evalution in Spring 2020. We follow by outlining the subsequent evaluation rounds of the program, from Fall 2020–Fall 2021. We end with an in-depth look into the Fall 2020 programmatic evaluation of the NEET program.

2.1. Pilot programmatic evaluation: Spring 2020

In Spring 2020, NEET leadership appointed the authors to pilot an evaluation of the NEET program, based on NEET educational resources and data already pre-collected from Fall 2018–Spring 2020. The period covered by this initial evaluation was before the first author had joined the program. The pilot objectives were to (a) evaluate selected aspects of the NEET program, (b) provide program leadership with suggestions for improving the program, and (c) inform recruitment efforts of students to the program. Guided by the four core principles of the program (see Section 1) and directed by program leadership, this first evaluation pilot focused on the following programmatic aspects: (a) curriculum and pedagogy, (b) the experience of NEET students, and (c) enrollment in and scaling of the program. The findings and suggestions resulting from this pilot led to the design of future programmatic evaluation iterations.

2.2. Subsequent programmatic evaluations: Fall 2020–Fall 2021

Following the pilot evaluation of Spring 2020, subsequent recuring programmatic evaluations of NEET covered the aspects mentioned in Table 1. To mitigate for potential bias with the curricular aspects of programmatic evaluations by the first author, the second author was involved with and reviewed all the work carried out by the first author. Data collection instruments were developed based on the programmatic success criteria described under section 2.

Table 1. Aspects covered in NEET programmatic evaluations from Fall 2020–Fall 2021.

Programmatic evaluation aspect	Fall 2020	Spring 2020	Fall 2021
Curriculum and pedagogy	X	X	X
NEET student experience	X	X	X
Implemention of key suggestions from previous report	X	X	X
Remote teaching and learning	X	X	
Program outreach (in and out of MIT)	X		X
Race and gender of NEET students		X	X
Alternatives to NEET senior student projects		X	X
Student recruitment to the program		X	X
Budget and spending	X		
Program scaling	X		

Table 2 details the sections and contents included in the programmatic evaluation reports.

Table 2. Template for a NEET programmatic evaluation report.

Section	Contents
Cover Page	Title; Authors; Date submitted; Submitted to
Executive Summary	Purpose; Background; Methodology; Key Findings; Key Suggestions
Background	About the NEET Program; Historical Context; Purpose of Evaluation; Scope of Evaluation; Key Terms
Methodology	Data Collection; Data Analysis; Limitations of Evaluation
Findings	Implementation of key suggestions from previous report; Other sub-sections depending on evaluation aspects
Suggestions	Implementation of key suggestions from previous report; Other sub-sections depending on evaluation aspects

Figure 1 describes the timeline followed for each programmatic evaluation.

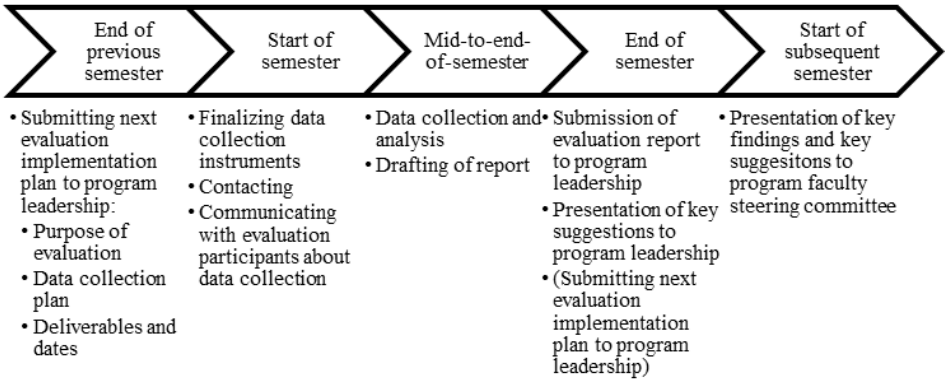

Figure 1. Timeline for one semestrierial programmatic evaluation study in NEET.

Findings of each report are treated by the team as formative feedback. The implementation of evaluators' suggestions from each report are then reviewed again in the following semester's evaluation. Figure 2 describes this formative process.

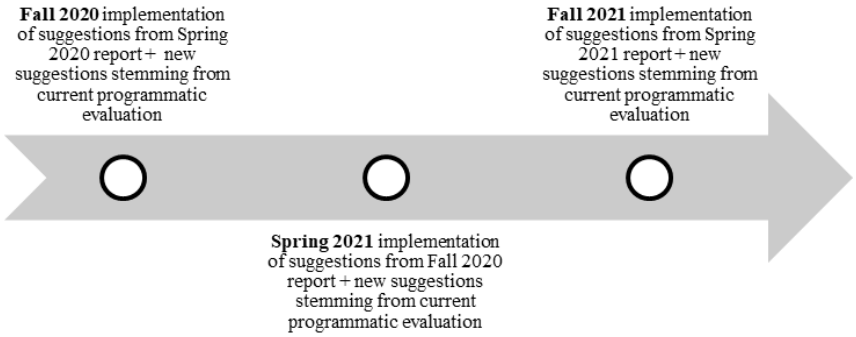

Figure 2. Formative process of implementating evaluators' suggestions included in NEET programattic evaluation reports and reviewing their implementaiton in the next evaluation.

2.3. Fall 2020: Presenting a full cycle of programmatic evaluation in focus

Halfway through Spring 2020, as the COVID-19 pandemic reached the United States of America, MIT announced a campus shutdown for the rest of the semester, a change from in-person to fully remote (virtual) teaching, and a change in the grading of all subjects (course) to pass/fail only. Remote teaching continued throughout Fall 2020. NEET's pivot to emergency remote teaching in Spring 2020, followed by planned remote teaching in Fall 2020, is detailed elsewhere [16].

The authors received MIT COUHES[4] exempt review approval (ID: E-2558) to collect data from program stakeholders, analyzing these data, and publishing the results of data analyses. All interview recordings were transcribed by CITI[5]-trained professionals. All the rules and practices for ethical research in education were followed by the Evaluators.

As Table 3 shows, data collection for this evaluation included interviews and surveys with the NEET program team, MIT Institutional Research[6] (IR) data on students, and MIT Registrar[7] subject evaluations by students. In this paper, we only provide summaries and analyses for data collected during Fall 2020 by the evaluators, i.e., the authors of this paper.

Table 3. Data collection for NEET programmatic evaluations in Fall 2020.

Data collection source or instrument	Collected by and during
Interviews with program team: • Three Program leaders • Five Thread faculty leads • One engineering education expert • One academic administrator	Evaluators, Fall 2020
Programmatic Evaluation surveys: • Survey of thread instructors (N = 6) • Survey of NEET students (N = 26)	Evaluators, Fall 2020
Past surveys: 1. Students applications to the NEET program (N = 96) 2. Survey of New Students 3. Survey of Enrolled Students 4. Subject[1] evaluation reports	1. NEET academic administrator 2. MIT Institutional Research 3. MIT Institutional Research 4. MIT Registrar
Fall 2020 NEET Subject syllabi for Fall 2020	Evaluators, Fall 2020
Fall 2020 NEET Ways of Thinking modules' descriptions	Evaluators, Fall 2020

[1] 'Subject' at MIT would be called 'course' in some other instutitions.

Interview transcripts were analyzed for content. We divided each response into topics by open-ended analysis. Next, we combined similar topics within and across the various interviews into single topics, and then categorized those into facilitators, obstacles, and desires.

[4] https://couhes.mit.edu/
[5] https://about.citiprogram.org/
[6] https://ir.mit.edu/
[7] https://registrar.mit.edu/

For the Survey of Thread Instructors, we calculated mean averages for each quantitative item in the survey. For qualitative items, we identified the most frequent similar response. The small sample (N = 5) and the brevity of responses precluded deeper analysis of item responses.

For the Survey of NEET Students, we calculated mean averages for each quantitative item in the survey. For qualitative items, we identified the most frequent similar response. The relatively small sample (N = 26) coupled with the heterogeneity of respondents in terms of degree years and NEET threads precluded deeper analysis of item responses.

For the student application to the NEET program, we used previous analysis carried out by NEET's engineering education expert. His analysis was open-ended and resulted in nine reasons stated by applicants for selecting specific thread/s as their first choice/s.

For both MIT IR surveys, we selected specific quantitative items which we deemed relevant to the aspects of the programmatic evaluation. We received from MIT IR a breakdown of responses to those items into 'NEET students' and 'non-NEET students', including sample numbers and mean averages.

For subject evaluation reports, we selected specific quantitative items which we deemed relevant to the 'remote learning' aspect of this evaluation.

For the NEET subject syllabi, we searched for (a) learning objectives and learning outcomes, (b) mentions of new machines and systems, and (c) mentions of NEET ways of thinking.

On February 1st, 2021, the evaluators submitted the evaluation report to program leadership. Shortly after this date, the evaluators presented their suggestions for improving the program, based on the results of the programmatic evaluation, to program leadership. On April 6, 2021, the evaluators presented their key findings and suggestions to the NEET faculty streering committee.

Evaluators' suggestions were divided into three timeframes of implementation: (1) short term implementation (here, by the end of the Fall 2020 semester), (2) average time implementation (here, by start of the Spring 2021 semester), and (3) long term implementation (here, by the start of the Fall 2021 semester). As an example, the Fall 2020 suggestions, in part, led to three major changes in the program curriculum, which were all fully implemented by Fall 2021: (a) the creation of a new program thread—Climate and Sustainability Systems, (b) the development and piloting of a new curriculum and learning progression for the NEET Ways of Thinking, and (c) the planning of a recruitment campaign for students to the program which took into considertion students' stated reasons for joining NEET.

3. Reflections and Recommendations

Evaluating a pilot undergraduate program like NEET over multiple semesters requires rigorous planning and specific expertise. We divide our recommendations to evaluators of similar programs into three categories: people, process, and data.

3.1. People

First, the team of evaluators should include expertise in (a) programmatic evaluation research methods, (b) the core curricular discipline, and (c) the apropriate state-of-the-

art pedagogies and instructional methods that should be employed in the program. If any of these expertise are not available, then outside experts can be brought in. Second, buy-in and cooperation from program faculty, instructors, and other stakeholders is crucial for obtaining the necessary data for evaluation, including access to students. This buy-in can be faciliated by program leadership, and careful explaining and transparency is absulutely necessary.

3.2. Process

Program leadership should collaborate with evaluation experts early on to come up with the apropriate evaluation design plan. Carefull pre-planning and ample time is needed for the experts to come up with the selection or even the new development of the right instruments. Once the evaluation rounds are ongoing, program leadership should remain actively involved at the start and end of each cycle in reviewing the (a) proposed budget for evaluation, (b) implementation plan, and (c) the evaluators' suggestions. We have learned that an additional, mid-semester review of suggestions from the previous evaluation report is preferable to a one-off review at the end of the semseter of the subsequent evaluation, because waiting an entire semester to review suggestions may mean some suggestions will not be properly implemented. When drafting an implementation plan for a specific evaluation, evalutors should be realistic with respect to the time, resources, and buy-in that are available, and have a clear understanding of the priorities for evaluation. Collecting large amounts of data is not valuable unless the time and resources exist to analyse, interpret, and act on them. It also raises the risk of having research participants to get over-researched and ending up not providing data of a great quality and quantity. Consulting with program leadership is vital for achieving this focus. While the very first evaluation pilot may be wide in scope and often treated as a test-bed regarding study setting and population, subsequent evaluations should gain more focus.

3.3. Data

To avoid disruptions and transgressions pertaining to data collection and use, evaluators should make sure to familiarize themselves with the rules and regulations in their specific instituion as pertaining to data collection from human subjects. Evaluators should also use data collection methods and instruments that can be used consistently in subsequent evaluation rounds. This helps to save time and to standardize the collection of data, easing comparisons between semesterial evaluations. While some aspects can vary between semesterial evaluations, many of these will likely remain the same. During the design stage of data collection, evaluators should search for existing institutional data to ensure no wasted efforts in data collection. In respect to this topic, evaluators should become aware about institutional policies in regards to the use of pre-collected research data.

References

[1] W. Karwowski and H. Parsaei, NAE Grand Challenges for Engineering in the 21st Century: Implications for industrial and systems engineering, *Proceedings Engineering Leaders Conference*, 2014, pp. 2-4.
[2] N.N., *NAE Grand Challenges for Engineering*, The National Academies Press, Washington, DC, 2017.

[3] A. Bagiati, V. Sakhrani, S. Sarma, and R. de Neufville, Approaching institutional transplantation through faculty development, *Proceedings of the SEFI 2012 Annual Conference*, Thessaloniki, Greece, September 23-26, 2012, https://www.academia.edu/1989469/Approaching_Institutional_Transplantation_through_Faculty_Development, accessed June 20, 2022
[4] G. M. Bubou, I. T. Offor, and A. S. Bappa, Why research-informed teaching in engineering education? A review of the evidence, *European Journal of Engineering Education*, 2017, 42:3, pp. 323-335, DOI: 10.1080/03043797.2016.1158793.
[5] S. Sarma and A. Bagiati, Current innovations in STEM education and equity needs for the future, *Imagining the Future of Undergraduate STEM Education Symposium*, Nov 13, 2020.
[6] National Research Council, *Education for life and work: Developing transferable knowledge and skills in the 21st century*. National Academies Press, Washington, DC, 2013.
[7] N.N., *The future of jobs report 2020*, World Economic Forum, Geneva. 2020.
[8] K. Ananiadou and C. Magdalean, *21st century skills and competences for new millennium learners in OECD countries*, Head of Publication Service, OECD, Paris, 2009.
[9] N.N., *Criteria for accrediting engineering programs, 2019–2020*, Accreditation Board for Engineering and Technology, 2019. Retrieved from http://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2019–2020/#outcomes
[10] W.G. Tierney (ed.), *The responsive university*, The Johns Hopkins University Press, Baltimore, 1998.
[11] R. Graham, *The Global State of the Art in Engineering Education*, Massachusetts Institute of Technology (MIT) report, 2018. http://neet.mit.edu/wp-content/uploads/2018/03/MIT_NEET_Global-StateEngineeringEducation2018.pdf, accessed June 20, 2022.
[12] R. Lavi, J. Lavallee, G. L. Long, N. Melenbrink, M. M. Salek, R. Shepardson, and A. Mitra, Revising the requirements of a cross-departmental project-centric undergraduate engineering program and launching of a new climate and sustainability-themed thread, *ASEE 2022 Annual Conference & Exposition*, Minneapolis, MN, June 2022.
[13] E. F. Crawley, A. Hosoi, and A. Mitra, Redesigning undergraduate engineering education at MIT – the New Engineering Education Transformation (NEET) initiative, *125th ASEE Annual Conference & Exposition*, Salt Lake City, UT, June 2018. Retrieved from: https://peer.asee.org/30923.
[14] E. F. Crawley, A. Hosoi, G. Long, T. Kassis, W. Dickson, and A. Mitra, Moving forward with the New Engineering Education Transformation (NEET) program at MIT – building community, developing projects, and connecting with industry, *126th ASEE Annual Conference & Exposition*, Tampa, FL, June 2019. https://peer.asee.org/33124, accessed June 20, 2022.
[15] E. F. Crawley, M. Bathe, R. Lavi, and A. Mitra, Implementing the NEET Ways of Thinking at MIT and assessing their efficacy, American Society for Engineering Education Annual Conference, Montreal, Canada, June 22–26, 2020. https://bit.ly/39Tl6dy, accessed June 20, 2022.
[16] R. Lavi, M. Bathe, A. Hosoi, A. Mitra, and E. Crawley, The NEET Ways of Thinking: Implementing them at MIT and assessing their efficacy, Advances in Engineering Education, 2021, https://advances.asee.org/the-neet-ways-of-thinking-implementing-them-at-mit-and-assessing-their-efficacy/, accessed June 20, 2022.
[17] T. Kassis et al., Pivot to remote teaching of an undergraduate interdisciplinary project-based program: Spring–Fall 2020, 2021 ASEE Virtual Annual Conference, 2021. https://peer.asee.org/pivot-to-remote-teaching-of-an-undergraduate-interdisciplinary-project-based-program-spring-fall-2020.pdf, accessed June 20, 2022.
[18] G. Stump, Y. G. Westerman, and K. Hall, Human skills: Critical components of future work. The Evollution. https://evolllution.com/revenue-streams/workforce_development/human-skills-critical-components-of-future-work/ , accessed June 20, 2022.
[19] N.N., Institutional self-study: Prepared for the New England Commission of Higher Education, MIT, August 2019. https://accreditation.mit.edu/sites/default/files/documents/2019MITself-study.pdf, accessed June 20, 2022.
[20], N.N.,Research & evaluation, Teaching and Learning Lab, https://tll.mit.edu/research-evaluation/, accessed June 20, 2022.
[21] N.N., Academic program review: Guidelines and procedures, Brown University, June 2012. https://www.brown.edu/web/documents/provost/Academic-Program-Review-Handbook.pdf, accessed June 20, 2022.
[22] N.N. Best practice in academic program review, Hanover Research, 2012. https://www.asanet.org/sites/default/files/hanoverresearch_bestpractices_programreview.pdf, accessed June 20, 2022.
[23] N.N., Guidelines for academic program assessment". Oswego State University of New York, https://www.oswego.edu/institutional-research/guidelines-academic-program-assessment, accessed June 20, 2022.