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The NEET Ways of Thinking: Implementing them at MIT and Assessing their Efficacy

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ABSTRACT

In Fall 2016, the School of Engineering at the Massachusetts Institute of Technology (MIT) chartered the New Engineering Education Transformation (NEET) initiative. NEET aims to educate young engineers to build the new machines and systems that will address societal needs of the 21st century. Students enter NEET in their sophomore year and join one of five threads, namely Advanced Materials Machines, Autonomous Machines, Digital Cities, Living Machines, and Renewable Energy Machines. Threads are cross-departmental pathways of subjects and projects in interdisciplinary areas. NEET students earn an SB degree in their declared major as well as a NEET Certificate in their thread, within the usual four-year duration. Enrollment in the program has increased from 28 students in Fall 2017 to 187 in Fall 2020. NEET students practice the 12 NEET Ways of Thinking, which are cognitive approaches for tackling complex challenges. Thus far, we have incorporated the Ways of Thinking into the program curriculum in two ways: (a) standalone Modules on four Ways of Thinking, i.e., Ethical Thinking, Creative Thinking, Critical Thinking, and Learning How to Learn, which were developed, piloted and taught in 32 sessions from Fall 2018–20 by MIT experts from outside of the program; and (b) an elective class last fall that introduced first-year students to the five threads and to four Ways of Thinking, i.e., Creative Thinking, Systems Thinking, Analytical Thinking, and Making. We learned from the emergency teaching pivot last spring and from remote teaching in fall, and now plan to launch another first-year class that will focus exclusively on Creative Thinking and Systems Thinking along with a semester-long challenge as well as introductory learning vignettes covering each Way of Thinking separately. In this paper we describe how the Ways of Thinking were and are being implemented, share key lessons we have learned, and describe our plans for further incorporation and assessment of the Ways of Thinking into the program.

THE MOTIVATION FOR THE NEW ENGINEERING EDUCATION TRANSFORMATION PROGRAM INITIATIVE

International and national bodies concerned with education and with economics have recognized the need for participants in today's workforce to possess a set of competencies for thriving in the 21st century. Appropriately, these competencies are often referred to as *21st century skills*. Some of these skills include collaboration, communication, critical thinking, and learning on one's own, among others [1], [2], [3], [4]. The need for students to acquire 21st century skills has been reflected in papers produced by the Organization for Economic Co-Development – OECD [3] and the US National Research Council – NRC [4]. More specifically in engineering higher education, ABET's Student Outcomes criteria for accreditation of engineering education programs also include some of these skills, for example, collaboration, communication, and the ability to learn on one's own [5].

Former MIT president Charles Vest who also served as president of the National Academy of Engineering has said that engineering science evolved through World War II and continued to move engineers away from practical engineering [6]. Researchers have claimed that undergraduate engineering curricula should equip alumni with the thinking skills required for facing current and future challenges, even in place of some content knowledge [7], [8]. For any higher education institution to be able to deliver this new education to its students, it must develop strategies for action which stem from its articulated vision [9]. Following a global benchmarking study commissioned by MIT-NEET [10], the Institute recognized the impending need to provide students with more opportunities for practical engineering and help them acquire those thinking skills.

THE NEW ENGINEERING EDUCATION TRANSFORMATION PROGRAM

This section is divided into four sub-sections: first, we describe the background of the NEET program. Next, we detail student enrollment in the program. We then proceed to describe the program requirements, followed by a description of projects students carry out in the program. Note that earlier papers have already covered in detail the thinking behind the NEET initiative, its goals, strategy, progress until mid-Spring 2019, initial student feedback and response, the project-centric approach and community development in two of the threads, and connecting with industry [7], [8].

Program Background and Launch

There were three fundamental artifacts that emerged from the evidence gathering, analysis, discussions, and deliberations in the first phase of NEET [7]:

1. What we have termed as the 'NEET Ways of Thinking', or Ways of Thinking: cognitive approaches for tackling complex challenges. These were formulated based on a global benchmarking

study [10], interviews with more than 40 senior managers in industry, and surveys of more than 40 MIT alums and previous research on this topic, all detailed previously [7]. There are 12 Ways of Thinking in total: analytical, computational, creative, critical, discovering, experimental, humanistic, interpersonal, learning how to learn, making, personal, and systems. See Table A in the Appendix for full descriptions of the Ways of Thinking.

2. The project-centric curricular construct
3. The concept of cross-departmental pathways we have termed as 'threads'. The five threads being piloted currently are named as follows: Advanced Materials Machines, Autonomous Machines, Digital Cities, Living Machines, and Renewable Energy Machines.

NEET is based on four core principles:

1. Our education should focus on preparing our students to develop the new machines and systems that they will build in the middle of the 21st century. In NEET, we use the words 'system' and 'machine' interchangeably, with 'machine' having the same meaning as 'technological system'.
2. We should help our students to prepare themselves to be makers and discoverers, and we should teach engineering fundamentals as a foundation for careers both in research and in practice.
3. We should build our education around the way our students best learn, engaging them in their learning, and implementing pilots to understand the desirable balance of classroom, project, and digital education for the digital natives.
4. In view of the speed of scientific and technological development, we should teach students how to think more effectively, and how to learn more effectively by themselves.

In Fall 2017, MIT launched the pilot NEET Program, aimed at educating young engineers to build new machines and systems for addressing societal challenges of the 21st century. The goal of NEET is to prepare students to become future entrepreneurs, innovators, makers, discoverers, and leaders [7].

Student Enrollment in the Program

NEET is voluntary and does not fulfill any requirements toward an engineering degree as prescribed by MIT. Students enter as sophomores and after successfully completing the entire three years of the program (as well their major) receive a NEET Certificate. As of Fall 2020, there were 187 students across sophomore, junior and senior years who had registered for NEET, with the first cohort of students in their senior year having completed the program at the end of the 2019–20 academic year. Though it is far too early to come to meaningful conclusions for the medium to longer term, the initial response is encouraging, as seen in Table 1.

Additionally, the NEET program attracts more women and about the same percentage of underrepresented groups when compared with average representation across MIT: approximately

Table 1. New student enrollment (sophomore year) in the NEET program From Fall 2017–2020.

Year enrolled in NEET (Class Year)	N sophomore students enrolled in NEET	% of all sophomore students who have declared engineering majors
Fall 2020 ('23)	99	~ 20%
Fall 2019 ('22)	77	~ 17%
Fall 2018 ('21)	52	~ 9%
Fall 2017 ('20)	28	~ 5%

Note. The number of sophomore students enrolled in the NEET program is taken at the start of the Fall semester (September). The number of sophomore students who declared their major as engineering is taken around mid-October.

68% of students enrolled in the program are women (compared to ~49% of MIT undergraduates), and approximately 32% are from underrepresented groups (compared to ~30% of MIT undergraduates).

Program Requirements

The Program includes projects, guest speaker sessions, and more traditional lectures and lab lessons to impart students with the knowledge and skills required for doing project work in their respective domains. Over the summer of 2020, we revised the requirements of each thread to integrate better and with less extra effort with students' various majors. We implemented these new requirements in Fall 2020. NEET students fulfill the new program requirements by completing one or two extra subjects (12–24 units or credits) beyond what is required in their major, while benefiting from project-based experience, interdisciplinary learning, hands-on activities, meetings with industry, and a community of students from different majors. Roadmaps for every allowed combination of thread and major are available on the NEET website[1]. Figure 1 shows one such roadmap for how a student studying for a Mechanical Engineering major might complete the program's Autonomous Machines thread over the last three years of their four-year degree. The extra classes on top of the major are 16.632 (6 units), 16.634 (3 units), and 16.84 (12 units), totaling at 21 units, or credits.

Student Projects in the Program

The majority of students' time in NEET is taken up by engineering projects of varying scope and complexity levels. In most threads, students would begin in sophomore year doing individual or pair-based projects, continue into junior year doing projects in small teams of three to five, and end in senior year doing projects in teams, only this time larger. Figure 2 provides a schematic of NEET's initial project-centric approach.

[1] Select a thread from the menu and scroll to the bottom of the page: https://neet.mit.edu/threads.

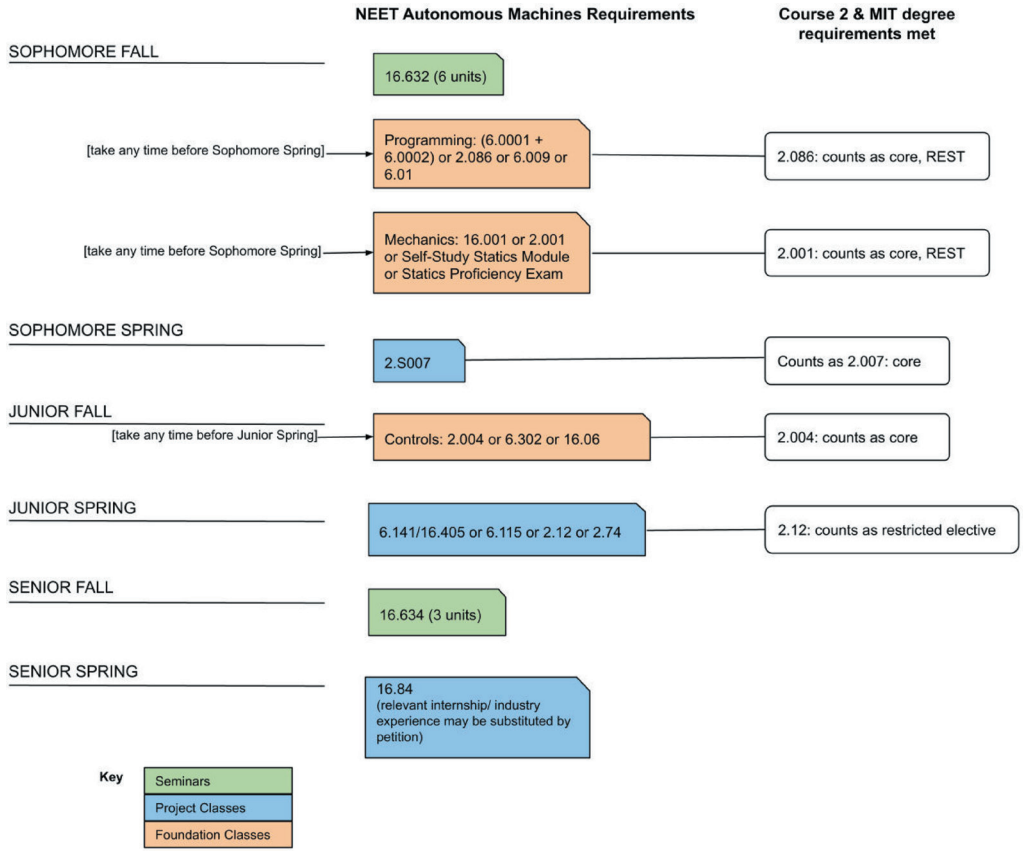

Figure 1. Roadmap for Autonomous Machines thread and Course 2 – Mechanical Engineering. Retrieved from https://neet.mit.edu/threads/am

Note. Serial numbers in the form of X.XX are subject numbers. REST is 'Restrictive Elective in Science and Technology'.

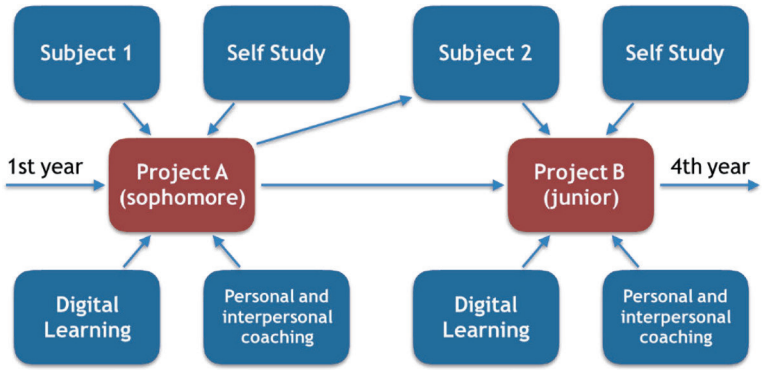

Figure 2. NEET Project-centric Approach.

Figure 3. Generic stages of a typical project in NEET.

Note. 'Conceive Solution' may be instructor- or student-directed, depending on the thread and year in the Program.

During projects, students conceive, design, develop, implement, and test machines and systems for solving problems taken from the real world. NEET offers MIT's undergraduate engineering students an opportunity to choose one of five application domains of 21st century engineering systems and then engage in projects within that domain. A project – the conceiving, designing, and testing of one system or one solution to a problem – may take one semester or an entire year, with both individual and team projects.

Figure 3 is a schematic representation of the stages of a typical project in NEET [11]. In practice, the process of carrying out a project is not linear; for example, while developing a solution it might become apparent that changes need to be made to the design. However, this schematic representation is useful for purposes of curricular and instructional design.

Table 2 contains a selection of projects from across the NEET program.

PREVIOUS AND CURRENT INCORPORATION OF THE NEET WAYS OF THINKING

This section comprises three sub-sections: first, we describe the motivation and background for the NEET Ways of Thinking. Next, we outline the initial approach we took toward incorporating

Table 2. Examples of NEET Student Projects.

Thread	Program year	Project example
Advanced Materials Machines	Junior	Design, fabricate, and evaluate a high-volume manufacturing process multi-part consumer product, i.e., a Yo-Yo
Autonomous Machines	Senior	Develop and program an autonomous flying drone for detecting structural instabilities inside of a building
Digital Cities	Sophomore	Assemble an air sensing unit, collect data with it, and analyze the data
Living Machines	Junior	Multi-lab molecular biomedical project involving the design, fabrication, and use of microfluidic devices
Renewable Energy Machines	Junior	Design and implement an energy and sustainability-related project

the Ways of Thinking in the program – the Ways of Thinking modules. We then proceed to another, different approach we took towards this incorporation – a pilot subject dedicated to several Ways of Thinking.

Since March 2020, due to the COVID-19 pandemic, teaching in the NEET program has been fully virtual. The virtual modality of teaching and the general uncertainty with regard to curricular planning have both affected our efforts in incorporating the NEET Ways of Thinking into the program curriculum.

Motivation and Background

The NEET Ways of Thinking are those cognitive approaches which NEET aims to imbue its undergraduate engineering students with. They were formulated based on a dedicated global benchmarking study commissioned by MIT [10], interviews with more than 40 senior managers in industry, and surveys of more than 40 MIT alums and previous research on this topic, all detailed previously [7]. There are 12 NEET Ways of Thinking: Learning how to learn; Making; Discovering; Interpersonal; Personal; Creative; Systems; Critical; Analytical; Computational; Experimental; and Humanistic. The definitions for the Ways of Thinking can be found on the MIT NEET website[2] as well as in Table A in the Appendix.

Initial Approach for Incorporating the Ways of Thinking: Modules

We opted to develop a standalone offering which we termed *Ways of Thinking Module*, or *module* for short. Modules were and are still taught as part of NEET subject classes, mostly in sessions which cover a single lesson (~90 minutes). This provides NEET students with an expanded range of learning opportunities beyond the mandatory and elective humanities and social science classes they take.

The formal incorporation into NEET of the Ways of Thinking began in Fall 2018. Resource experts from the School of Humanities, Arts and Social Sciences and the School of Architecture and Planning were invited to develop standalone modules for specific Ways of Thinking, tailor them to specific project classes and deploy them during two-hour time slots. For example, faculty and instructors from the Department of Linguistics and Philosophy and from the Gordon Engineering Leadership (GEL) program developed and taught a session on Ethical Thinking—part of the 'Personal' Way of Thinking. A single exception to this modular, standalone approach was the involvement of the Creative Way of Thinking experts in co-instruction on one project class which was shared by the junior year of two different threads in NEET. We believe that this is a sustainable approach since the resource experts will keep building on new knowledge in those Ways, much of it created through their research, practice, and scholarship.

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

Table 3. Ways of Thinking modules taught in NEET from Fall 2018–2020.

Way of Thinking Module	MIT entity involved in development and instruction of module	Program thread and student year			
		Fall 2018	*Fall 2019*	*Spring 2020*[a]	*Fall 2020*[b]
Creative	School of Architecture and Planning	–	AM: Jun.; Sen. AMM: Soph. REM: Soph.	–	–
Critical[c]	Program in History, Anthropology, and Science, Technology, and Society	–	AM: Soph.; Jun.; Sen. LM: Soph.; Jun.; Sen.	–	DC: Soph.; Jun. LM: Soph.
Ethical Thinking[d]	Department of Linguistics and Philosophy	AMM: Soph. AM: Soph.; Jun. LM: Soph. REM: Soph.	AM: Soph.; Jun. LM: Soph. AMM: Soph. REM: Soph.	LM: Jun.; Sen. AMM: Jun.	AM: Sen. LM: Jun.; Sen.
Learning how to learn	MIT Libraries	–	AM: Soph. LM: Soph. REM: Soph.	–	–

[a]Spring 2020 implementations were interrupted one week before Spring Break due to COVID-19 pandemic, [b]Fall 2020 modules were taught remotely, [c]Module contents related to the 'humanistic' Way of Thinking, [d]Module contents related to the 'Personal' Way of Thinking.

Note. AMM is 'Advanced Materials Machines', AM is 'Autonomous Machines', DC is 'Digital Cities', LM is 'Living Machines', and REM is 'Renewable Energy Machines'. Ways of Thinking modules were not taught in Spring 2019. Four NEET non-specific subject classes regularly have instructors from MIT Comparative Media/Writing, exercising students' 'Interpersonal' Way of Thinking: 6.141/16.405 (AM Junior), and 3.042, 2.013/2.733, and 2.014/2.734/2.019 (AMM Junior). Serial numbers in the form of X.XX are subject numbers.

Table 3 summarizes the various Ways of Thinking modules developed and taught to NEET students by MIT experts outside of NEET from Fall 2018–2020.

Table 4 outlines the learning objectives for three of the above Ways of Thinking: Ethical Thinking (personal way of thinking), Critical, and Learning how to Learn. Each session with each Way of Thinking had its own list of expected learning outcomes, depending mostly on the year in the program (sophomore, junior, or senior) where the session was taking place.

Evaluative assessment of the Ethical Thinking module was carried out by the Ethical Thinking module experts from the Department of Linguistics and Philosophy in MIT for the Fall 2018 Ethical Thinking module sessions, by way of questionnaires handed to students at the end of each session. As Table 5 shows, student feedback on the Ethical Thinking module sessions was strongly positive.

Students were also asked to provide free form comments and feedback. It was here that not only positive, but also some constructive comments were made. Table 6 summarizes the themes of these comments.

We provide more details on the Ethical Thinking module in another paper [12]. While useful for purposes of reviewing and improving upon the Ethical Thinking module specifically, the above assessment did not enable NEET as a program to improve upon the integration of the Ways of Thinking into its curricula across the various threads. Based on the assessment of the Ethical Thinking module sessions

Table 4. Learning objectives of Ways of Thinking modules.

Way of Thinking	Learning objectives
Ethical Thinking[a]	• Develop a sense of proximity between their engineering work and ethical issues • Recognize when an engineering decision has ethical implications • Employ ethical reasoning to navigate engineering decisions • Assess the impact of engineering decisions on personal and societal contexts
Critical[b]	• Conceptualize seemingly closed autonomous systems as heteromated socio-technical systems with submerged human choices • Actively recognize the benefits and costs of different forms of expertise • Recognize and respond to the competing politics of technical systems and choices
Learning how to Learn[c]	• Recognize specific contexts in which knowledge exists, knowing that it does not exist in a vacuum • Identify different kinds of information and environments within which types of knowledge exist • Use appropriate tools and strategies to locate and use information sources for learning • Identify unsolved problems and use that to articulate what else they need to know or understand • Develop and vet their ideas and theories about a research problem to guide their work • Understand social biases and how they impact and influence knowledge and innovation • Recognize larger societal and historical implication of their work and the work of others in their field • Realize their own agency and develop strategies and practices that influence equity in accessing and benefitting from human knowledge

[a] Taken from report by Ethical Thinking (Personal Way of Thinking) experts at MIT: Alex Byrne, Milo Phillips-Brown, and Marion Boulicault from the Linguistics and Philosophy Department and James Magarian from the Gordon Educational Leadership (GEL) Program, [b] Taken from report by Critical Way of Thinking experts at MIT: Jennifer Light and Marc Aidinoff from the Program in Science, Technology, and Society, [c] Taken from report by Learning how to learn Way of Thinking experts at MIT: Karrie Peterson and Elizabeth Soergel from MIT Libraries.

in Fall 2018, and on our own review of the content of all four modules as well as of syllabi related to the program, we derived some key lessons for the incorporation of the Ways of Thinking into the program:

1. Ways of Thinking were not taught explicitly outside of the module sessions, in any thread, with one exception being communication (part of 'interpersonal).

Table 5. Students' feedback on Ethical Thinking modules – Fall 2018.

	Sophomore (N = 17)		Junior (N = 25)	
Statement	***M rating***[a]	***% high rating***[b]	***M rating***[a]	***% high rating***[b]
This seminar session has inspired me to further develop my sense of moral responsibility	4.3	82	4	78
...has helped me to be able to envision ways in which an engineer can face conflicting pressures on the job	4.5	94	4.1	78
...has helped me to be able to test whether decisions I make as an engineer align with my values	4.2	82	3.8	67
I believe it is worth MIT engineering students' time to participate in this session	4.7	94	3.8	78

[a] Level of agreement with statement, from 1–5 in whole numbers, [b] score of 4 or 5 out of 5.
Taken from report by Ethical Thinking (personal way of thinking) experts at MIT: James Magarian from the Gordon Education Leadership Program at MIT, and Milo Phillips-Brown and Marion Boulicault from the Philosophy and Linguistics Department at MIT.

Table 6. Students' feedback on Ethical Thinking module sessions: Fall 2018.

Themes Identified in Students' Comments	Sophomore (N = 17)	Junior (N = 25)
Positive	• A general sense that the session was worthwhile and enjoyable • Session helped students make connections between ethics concepts and real-world • engineering scenarios • Session inspired students to think more deeply about ethics; to explore ethics further going forward	• The session engendered a sense that ethical implications are proximal to students' • own work as engineers • Students benefited from group work
Constructive	• The session felt too short or abbreviated • The session was not as personalized for individual learning needs as students desired	• The session competed with time sensitive, end-of-term assignments • The session was not as dynamic as it could have been

2. Some modules included the same topics. For example, some Creative and Learning how to Learn sessions both covered stakeholder management.
3. Resource experts from different departments and disciplines may use the same terms differently. For example, the Critical (humanistic) and Ethical (personal) Ways of Thinking experts both used the word 'critical thinking' but gave them different meanings.
4. On the whole, the Ways of Thinking experts recognized the need for integrating their material into project syllabi and specific stages of projects.
5. Examples of ethical situations need to be more specific to the thread domain, e.g., for the Autonomous Machines thread, to autonomy and robotics.
6. Some sessions were constrained to 60 minutes, and others to 90 minutes. Going forward, thread instructors should ideally allow 90 minutes of classroom time.
7. The 90-minute version of the session includes substantive coverage of a common set of "moral lenses" that can be used to evaluate specific decisions. This coverage includes time to provide examples of decision testing, and to debate/discuss the decision testing with students. Student feedback points to the need to include this content in sessions.
8. Sessions would be better if scheduled earlier in the term at times that do not compete with other student assignments.
9. In future seminars, instructors should include more dynamic presentations. Additional group work, which students expressed liking, may also help in this regard.

Subsequent Approach for Incorporating the Ways of Thinking: Dedicated Classes

In preparation for Fall 2020, MIT's Vice Chancellor had requested programs and departments around MIT to offer discovery classes to first-year students, with the goal of providing those students with

opportunities to explore various academic interests. NEET responded to this challenge by piloting a new approach which would leverage the program's resources and provide a complementary addition to the NEET Ways of Thinking modules. This effort resulted in the in-house development and implementation of a first-year class (subject) for three units (credits) in Fall 2020 titled *SP.248 Discover the Magic of the Ways of Thinking: NEET!* This subject was planned and taught as a virtual class, as MIT first-year students were off-campus throughout Fall 2020 due to the COVID-19 pandemic. This class was the first and thus far only NEET class offered to first-year students, as the NEET program is for sophomores, juniors, and seniors. SP.248 was led by NEET Lecturer and Curriculum Designer Rea Lavi, with five NEET thread instructors functioning as his co-instructors. The learning objectives of this subject were as follows:

1. Students will understand key concepts about Analytical Thinking, Creative Thinking, Making, and Systems Thinking.
2. Students will be able to relate these concepts to specific methods, tools, and techniques.
3. Students will be able to apply methods, tools, and techniques they learned to novel challenges.

The class introduced students to the NEET Ways of Thinking, with particular focus on creative thinking, systems thinking, analytical thinking, and making. The specific Ways of Thinking were selected by the instructors based on their own preferences, expertise, and correspondence with their thread. Each Way of Thinking was afforded two to four weeks, during which the Lead Instructor and Co-Instructor taught individual students and student teams through an interdisciplinary challenge that focused on one thread domain and on one Way of Thinking. Table 7 summarizes the Ways of Thinking, threads, and challenges covered by this subject.

Student response to this class far exceeded program expectations for a class with a pass/fail grade: 54 students completed the classes out of 61 who attended the first lesson, and the overall submission rate of assignments was nearly 100% for teams, and ~90% for individual students. The class also elicited students' interest in the NEET program, with 13 out of 54 students asking to be added to a 'preregistration' applicants' list.

Table 7. SP.248 Discover the Magic of the Ways of Thinking: NEET! contents.

Thread	Way of Thinking	Challenge
Advanced Materials Machines	Making	Molding and casting a simple figurine[1]
Autonomous Machines	Analytical	Formulating a search strategy for a mini-robot car to detect balls on a grid using sensors
Digital Cities	Creative	Generating ideas for an urban problem related to COVID-19 (dog walking in Cambridge, MA)
Living Machines	Systems	Choosing parts for a microfluidic device in order to perform a given function
Renewable Energy Machines	Systems	Describing energy production systems

[1] An 'activity kit' was shipped to each student's mailing address.

Based on student activity during and feedback on the SP.248 class in Fall 2020, we derived several implications and suggestions for the incorporation of the Ways of Thinking into the program:

1. There seems to be high demand among first-year students for learning about Ways of Thinking.
2. Students submitted a higher quality of work in team assignments than they had in individual assignments.
3. It was possible to assess students for various facets of the Ways of Thinking, including self-efficacy, conceptual understanding, and applicative ability.
4. Some students commented that not enough time was spent on either Way of Thinking.

Based on the implications and suggestions derived from our experience with teaching the SP.248 class, it is apparent that SP.248 on its own can neither provide students with an in-depth understanding of the fundamental concepts involved nor with substantial expertise in the application of related approaches though it could continue to serve as an engaging way to kindle first-year student interest in the Ways of Thinking. A logical next step in teaching first-year students the NEET Ways of Thinking would to be to develop a project-based approach with focus on integrating Ways of Thinking together. We have recently begun planning for another first-year class which will be challenge-based and focus on two Ways of Thinking, namely Creative Thinking and Systems Thinking. The provisional title for this class is 'Applying Creative Thinking and Systems Thinking to Climate and Sustainability Challenges' and it will be launched in Spring 2022. The class will be housed in the Department of Nuclear Science and Engineering Department at MIT School of Engineering as a six-unit special subject over one semester. Students enrolled in this class will tackle a challenge from the 'Decarbonizing Ulan Bator' project in the Renewable Energy Machines thread. The class will not only help foster first-year students' creative thinking and systems thinking but will also afford students the opportunity to tackle a real-world problem and interact with NEET students and faculty.

PLANNED INCORPORATION AND ASSESSMENT OF THE WAYS OF THINKING

It is too early in the life of the program to tell what the overall commitment will be for incorporating all 12 Ways of Thinking across the five threads and three years of the program. To ensure the sustainability of the program, we will identify domain experts such as those who are developing and teaching the Ways of Thinking modules, as well as use in-house resources and expertise. We plan to work more closely with those module experts in order to be able to transition into teaching some if not all the material ourselves, with the module experts continuing as designers and new content developers.

This section outlines our plans for (a) the Ways of Thinking modules and first-year Ways of Thinking classes (SP.248), (b) integrating the Ways of Thinking with student projects and assessing the efficacy of this integration, (c) coordinating the Ways of Thinking across years in the program, and (d) maintaining the sustainability of these efforts.

Plans for the Ways of Thinking Modules and Classes

The Ethical Thinking and Learning how to Learn modules will continue to take place in Spring 2021. SP.248 has been renewed for Spring 2021, and we plan to continue with the same format and content as previously.

Integrating Ways of Thinking into Projects

Integrating the Ways of Thinking into the fabric of student projects is strongly desirable. However, doing so will require extensive study and discussions and buy-in from various stakeholders. Our guidelines for formulating a strategy for incorporating the Ways of Thinking into student projects will be (a) the four core principles of the NEET, detailed under 'Program Background and Launch' above, and (b) ensuring the sustainability of these efforts in the program.

We plan to study programs similar to MIT's and learn from their experience of what worked and what has not worked for them. Table 8 shows the results of a preliminary survey we have carried out

Table 8. Undergraduate engineering education programs like NEET.

Institute	Country	Program name	Program type	Other relevant attributes
Aalto University	Finland	Aaltonaut Bachelor's Minor Programme on Interdisciplinary Product Development	Minor degree	–
Chalmers University of Technology	Sweden	Tracks	One-year optional course (co-curricular)	• Student-selected themes (tracks) with project work • Can select same/different theme each year
Delft University of Technology	Netherlands	B.Sc. Aerospace Engineering	Three-year B.Sc. degree	–
Minnesota State University Mankato	MN, USA	Iron Range Engineering	Four-year degree	• Student-selected focus areas in degree • Working on real industry projects
Olin College of Engineering	MA, USA	Engineering Degree Program	Four-year degree	Student-designed degree, combining college-wide requirements with elective classes
Pontifical Catholic University	Chile	Major in Engineering, Design, and Innovation	Major in four-year B.E.Sc.	• Wide in scope: from creation of opportunity to prototyping
Singapore University of Technology and Design	Singapore	Engineering Systems and Design Undergraduate Programme	Four-year degree	• Client-facing curriculum: solving problems for real clients) • Five focus tracks
University College London	UK	The Integrated Engineering Programme	Four-year curricular framework across degrees	• A set of core curriculum elements taught alongside discipline-specific components throughout degree • Skills delivered within the context of engineering problem solving

Table 9. Potential Assessments of Ways of Thinking in NEET.

Type of assessment	Assessor	Intended purpose	Potential assessment instrument
Self	Student	Facilitate self-understanding	Self-efficacy form[1] [13]
Formative	Instructor	Guide teaching in real (or near-real) time	Representation (model) of topic/ system/phenomenon[1] [14]
Summative	Instructor	Evaluate actual class outcomes versus intended learning objective and outcomes	In-class examination
Evaluative	Evaluator outside of the program	Evaluate the success of the program or thread versus its objectives	Programmatic evaluation [15]

[1] The citations provided are specific to the Systems Thinking.

of such programs. We looked for programs that exhibit a combination of the following attributes to some degree: (a) undergraduate-only, (b) last for at least a year, (c) engineering focused, (d) project-centric, (e) features interdisciplinary teamwork, and (f) explicitly mention the learning of skills other than technical/traditional engineering skills.

Plans for the Assessing the Ways of Thinking

We intend to further develop and integrate assessment across threads. The assessment can be carried out with any combination of the following: person (perceptions, attitudes, and so forth), process (cognitive or physical), product (artifact/machine), and environment (curriculum, methods, instructors, classroom, and so forth). Table 9 summarizes our future intentions for assessment in NEET.

Coordinating the Ways of Thinking Across Threads

As a program within MIT, we have decided to focus on five Ways of Thinking, namely Creative Thinking, Learning how to Learn, Personal Skills and Attitudes (including ethical thinking), Making, and Systems Thinking. All twelve Ways of Thinking are widely taught across MIT and we did not want to duplicate those efforts. We chose to prioritize the above five Ways of Thinking because they are core to NEET's approach. Content design and development for these prioritized Ways of Thinking will be led, as before, by experts from across MIT, with the involvement and support of NEET staff.

We intend to coordinate the incorporation of Ways of Thinking across thread years, so that within each thread there will be a similar progression of Ways of Thinking being introduced. The general approach will be to introduce NEET students to the Ways of Thinking during their sophomore year by way of introductory sessions with domain-specific examples, and then in their junior or senior year provide students with more advanced concepts, specific methodologies, and personal or team consultation to implement the Ways of Thinking in their junior or senior projects. This coordination

would build a 'just-in-time' progression for NEET students across three years, help the NEET team with designing tools, activities, and syllabi, and allow for better knowledge sharing across threads. We have also begun the development of learning vignettes for three Ways of Thinking—Creative Thinking, Learning How to Learn, and Ethical Thinking—together with other departments at MIT. Each learning vignette centers on one Way of Thinking and is a combination of a video and a reflective assessment. The role of these vignettes is to provide NEET sophomore students with an introduction to the NEET Ways of Thinking. NEET will continue to deepen its relations with faculty in various departments across MIT and thus ensure stronger cooperation and sharing of resources.

CONCLUSION

In this paper, we described the New Engineering Education Transformation (NEET) program, with specific focus on piloting the Ways of Thinking – cognitive approaches that students require to become entrepreneurs, innovators, makers, and discoverers. Seven of the 12 Ways of Thinking have already been piloted: Analytical; Creative; Critical; Making; Learning how to Learn; Personal (specifically ethical thinking); and Systems. The lessons we learned from their implementation are helping guide future design and implementation. With project-centric curricula and 21st century skills being introduced to undergraduate engineering education worldwide [10], we intend to continue designing, developing, and implementing more Ways of Thinking into NEET and in a more integrative manner that is contextual to the application domain covered by each thread to better prepare students for the challenges they will face in employment, entrepreneurship, or graduate studies.

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APPENDIX: NEET WAYS OF THINKING

Table A. NEET Ways of Thinking and their Descriptions.

Way of Thinking	Description	Resource Experts at MIT
Learning how to learn	The motivation and curiosity, reflected in behavioral patterns, to think and learn on their own initiative, throughout their lifetime	Libraries
Making	Innovating, by inventing and bringing about artifacts that have never before been in existence: Conceiving (understanding needs and technology, and creating concept), designing, implementing, and operating products and systems that deliver value	School of Engineering — Makerspaces
Discovering	Advancing the knowledge of our society and world by exploring, identifying, and generating new learning, often by conducting research that employs scientific methods and leads to new fundamental discoveries and technologies	School of Science
Interpersonal Skills	Engaging with and understanding others: communicating, listening, dialog and emotional intelligence, working in and leading teams, collaboration and networking, advocacy, and leading change	Sloan School of Management
Personal Skills and Attitudes	Initiative, judgment, and decision making; responsibility and urgency; flexibility and self-confidence; acting ethically and with integrity; social responsibility; dedication to lifelong learning	School of Humanities, Arts & Social Sciences; Gordon Engineering Leadership (GEL) program
Creative Thinking	Forming something new and somehow valuable, for example by focusing thought, incubating new ideas, illuminating them in conscious awareness, and verifying	School of Architecture and Planning
Systems Thinking	Predicting emergence of the whole by examining of inter-related entities in context, in the face of complexity and ambiguity, for homogeneous systems and systems that integrate multiple technologies	Institute for Data, Systems and Society (IDSS)
Critical and Metacognitive Thinking	Assessing the worth or validity of something that exists, by analyzing and evaluating information gathered from observation, experience, or communication	School of Humanities, Arts & Social Sciences
Analytical Thinking	Working systematically and logically to break down facts and resolve problems, identify causation, and anticipate results, often by applying theory, modeling, and mathematical analysis	Departments
Computational Thinking	Using computation to understand physical, biological, and social systems by applying the fundamental constructs of computer programming (abstractions, modularity, recursion), data structures, and algorithms	Department of Electrical Engineering and Computer Science
Experimental Thinking	Conducting experiments to obtain data: selecting measurements, determining procedures to validate data, formulating and testing hypotheses	Departments
Humanistic Thinking	Developing and exploiting a broad understanding of human society, its traditions, and institutions: knowledge of human cultures, human systems of thought, the social, political, and economic frameworks of society; and modes of expression in the arts	School of Humanities, Arts & Social Sciences