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Work-in-Progress: The Unique Impact of an Interdisciplinary Experiential Learning Program on Undergraduate STEM Students' Career Readiness

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Amitava 'Babi' Mitra, Ph.D. enjoys visioning, designing, setting up and operationalizing innovative 'start-up' educational initiatives and has over thirty years' experience in institution and program building, higher education, corporate e-learning, and distance education. He is the founding Executive Director, New Engineering Education Transformation (NEET) at the Massachusetts Institute of Technology, USA, an initiative that has come a long way since its launch as a bold educational endeavor in 2017. The academically and demographically diverse NEET student community now comprises 248 sophomores, juniors and seniors — larger than most majors — pursuing 21 majors in 11 departments, encompassing all five schools at the Institute.

Mitra transformed a small e-learning R&D group into the profitable Knowledge Solutions Business at NIIT, Inc., Atlanta, Georgia, USA as its Senior Vice-President. He is a founding member, Board of Governors of an NGO, Pan Himalayan Grassroots Development Foundation, Kumaon, India and as the founding Dean, School of Engineering & Technology, BML Munjal University (BMU), India during 2013-16 launched 'Joy of Engineering', a first-year hands-on course designed to get students engaged with engineering.

Mitra is regularly invited to deliver keynote addresses and be a panelist at global conferences focusing on engineering education. He is on the Editorial Board, European Journal of Engineering Education, 2023, and a co-Editor, Special Issue on Interdisciplinary Learning and Transforming Engineering Education, to be published by EJEE early in 2025. He was an invitee at the Integrated Engineering Education International Symposium (IEEIS 2024) convened by University College London, UK in 2024.

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1. Introduction

1.1. Theoretical background

1.1.1. 21st century skills

The current era is marked by an increasing need for a new set of skills, often named generic skills or 21st century skills. Education researchers have recognized this need [1], as have educational bodies [2] and economic bodies [3]. However, fostering 21st century skills in undergraduate science, technology, engineering, and mathematics (STEM) students remains a challenge [4], with STEM graduates at times underprepared for what present-day STEM professions require [5]. An indication for this under-preparedness is the finding that students' levels of 21st century skills rarely correspond to their academic achievement levels [6]. Therefore, changes to STEM curriculum, instruction, and assessment are required in higher education to prepare students for the current economy, as highlighted by education researchers [4,7] and by US and international bodies concerned with engineering education [8,9].

A classification of 21st century skills carried out by [10] based on (a) a review of the literature on 21st century skills from ABET [2], the US National Research Council [8], the Next Generation Science Standards [11], and the US Labor Department [5] resulted in a list of 14 skills. Exploratory factor analysis of a survey about those 21st century skills distributed among nearly 1,600 final-year students and alumni of a university resulted in a classification of those skills into three factors, or categories: domain-agnostic (interdisciplinary) skills, interpersonal or 'soft' skills, and STEM-specific skills. Table 1 shows the list of skills and their categories.

Table 1. Classification of 21st century skills based on [10].

Domain-agnostic	Interpersonal	STEM-specific
• Complex problem-solving • Critical thinking • Individual learning • Question posing	• Creativity • Collaboration • Intercultural communication • Entrepreneurship • Oral communication • Written communication	• Engineering design • Experimenting and testing • Applying STEM knowledge • Systems thinking

1.1.2. Role models

Role models can provide encouragement and promote a sense of belonging and self-efficacy for STEM educational attainment, particularly for individuals who feel connected to the role model [12,13]. Role models motivate students by demonstrating that goals are attainable. They are directly involved in an individual's life, providing encouragement, as well as access to professional information and networks, skills, and social networks [14]. [15] showed that STEM undergraduate students benefited from mentors who cultivated their metacognitive abilities and higher order thinking skills. Studies of scientists, physicians, and science and engineering higher education students found that social support, including role models, had promoted their aspirations [16] and achievements [17,18].

1.2. New Engineering Education Transformation at Massachusetts Institute of Technology

Launched in 2017 as a pilot initiative, the New Engineering Education Transformation (NEET) program emerged from an initiative at Massachusetts Institute of Technology (MIT) to revitalize its undergraduate engineering education. As a cross-departmental extracurricular venture, it emphasizes integrative, experiential learning to foster skills, knowledge, and attributes vital for scientists and engineers grappling with 21st-century challenges. By October 2023, 248 students spanning sophomore to senior years at MIT had enrolled in the program.

NEET is guided by the principles that education should (a) prioritize readiness for technological innovation, (b) equip students for both theoretical and practical engineering pursuits, (c) align with contemporary learning methodologies, and (d) promote independent thinking and learning.

The program’s principles inform the program's curriculum and pedagogy, which are organized into four interdisciplinary tracks named ‘threads’: Autonomous Machines, Climate & Sustainability Systems, Digital Cities, and Living Machines. Each thread equips students with the ability to develop, operate, design, and test novel technologies and/or conduct novel scientific research through cross-departmental teamwork and hands-on projects, leveraging cutting-edge methodologies and tools.

Distinct from experiential learning programs at MIT, NEET is characterized by its multi-year duration and interdisciplinary nature, facilitating collaboration on progressively complex projects. These attributes enable students to acquire specialized proficiencies aligned with their chosen NEET thread. Participation in NEET is voluntary and does not confer a degree or constitute a major or minor at MIT; rather, students receive a certificate upon completion.

More information on the program and its history can be found in previous publications [19-25].

1.3. Undergraduate Research Opportunities Program at Massachusetts Institute of Technology

Undergraduate Research Opportunities Program (UROP), launched in 1969, is a long-established experiential learning program at MIT where undergraduate students conduct research under a faculty member. While voluntary like NEET, more than 90% of MIT’s graduating seniors participated in at least one research project or study over one or two semesters.

1.4. Research objective

The aim of this study is to evaluate the impact of NEET on its participants' career readiness, on its own and as compared with UROP.

The research questions (RQs) for this study are as follows:

- RQ1: What were the contributions of NEET and of UROP to the development of participants’ 21st century skills?
- RQ2: What was the importance of 21st century skills for participants’ career success?

- RQ3: What role models, if any, did participants encounter in NEET and outside of it at MIT?
- RQ4: How satisfied are participants in their current role?

We limited this study to the two founding threads of NEET: Autonomous Machines and Living Machines. We chose NEET's founding threads because they have gone through fewer changes in curriculum in recent years when compared with newer tracks and because they had the largest potential pools of NEET alumni—four cohorts from 2020-2023.

2. Methods and Materials

2.1. Data collection

This study received approval from MIT's institutional review board for human subject research, E-5414.

To answer the RQs for this study, we designed an online survey that included the following sections:

1. Informed consent to participate in the study (with the option to agree or disagree).
2. Demographic details, including census details (ethnicity, gender, etc.) and academic credentials.
3. Experience at MIT, which covered items related to career readiness: 21st century skill development and finding role models.
4. Current career, which covered items related to career readiness, including a list of 21st century skills.

We used email and social media to reach alumni of NEET, based on existing contact details we had stored previously. As of the date of submitting the manuscript, 16 former alumni of NEET have responded to the online survey.

2.2. Data analysis

Since the study sample (N = 16) was not large enough to conduct inferential statistical testing, we provide descriptive statistics instead:

- Development of 21st century skills at NEET when compared with UROP
- Importance of 21st century skills for career success
- Role models encountered at MIT, in NEET and outside of it
- Overall contribution of MIT to career readiness
- Career satisfaction

3. Findings

3.1 Demographic and academic details

Table 2 summarizes participants' demographic details.

Table 2. Demographic details.

Category	Sub-category	N
Gender	Women	11
	Men	5
Ethnicity	Asian	6
	Hispanic or Latino	3
	White (inc. Middle Eastern)	4
	White and Asian	1
	White and Latino	1
	Not specified	1

Table 3 summarizes participants' details as they pertain to MIT and NEET.

Table 3. Details related to MIT and NEET.

Category	Sub-category	N
Year of graduation from MIT	2020	5
	2021	2
	2022	4
	2023	5
MIT major	Bioengineering	2
	Biology	2
	Computer science	5
	Mechanical engineering	6
NEET thread	Autonomous Machines	10
	Living Machines	6

3.2. Career readiness

3.2.1. Development of 21st century skills at MIT and in NEET

Table 4 summarizes participants' self-reported degree of skill development at MIT.

Table 4. 21st century skill development at MIT.

Skill	Self-reported degree of skill development (1 = ‘not at all’ to 4 = ‘very much’)		
	Min.	*Max.*	*Mode*
Applying knowledge to problems	3	4	4
Complex problem-solving	2	4	4
Collaboration	2	4	4
Creativity	2	4	3.5
Critical thinking	3	4	4
Experimenting and testing	2	4	4
Engineering design	2	4	4
Entrepreneurship	1	4	2
Formulating questions	2	4	3
Intercultural understanding	1	4	3.5
Learning by oneself	2	4	4
Spoken communication	2	4	4
Systems thinking	2	4	4
Written communication	1	4	3

Table 5 summarizes participants’ number of responses regarding which experiential learning programs at MIT developed their 21st century skills.

Table 5. Significant contribution of NEET and of UROP to 21st century skill development at MIT.

Skill	*NEET*	*UROP*
Applying knowledge to problems	11	11
Complex problem-solving	9	9
Collaboration	12	4
Creativity	9	8
Critical thinking	7	8
Experimenting and testing	5	9
Engineering design	13	7
Entrepreneurship	7	4
Formulating questions	6	7
Intercultural understanding	4	5
Learning by oneself	10	8
Spoken communication	13	3
Systems thinking	10	4
Written communication	10	3

3.2.2. Importance of each 21st century skill to career success

Table 6 summarizes participants' self-assigned importance of each 21st century skill to their career success. Participants tended to consider all the listed skills as having high or very high importance, except for entrepreneurship.

Table 6. Self-reported importance of 21st century skill to career success.

Skill	Importance to career success (1 = 'not important at all' to 4 = 'very important')		
	Min.	*Max.*	*Mode*
Applying knowledge to problems	3	4	4
Complex problem-solving	3	4	4
Collaboration	3	4	4
Creativity	3	4	4
Critical thinking	2	4	4
Experimenting and testing	3	4	4
Engineering design	1	4	4
Entrepreneurship	1	4	1.5
Formulating questions	2	4	4
Intercultural understanding	2	4	3.5
Learning by oneself	2	4	4
Spoken communication	3	4	4
Systems thinking	2	4	4
Written communication	1	4	4

3.2.3. Overall contribution of NEET to career readiness

In response to the item "My experience in NEET helped prepare me for my career in ways that my other experiences at MIT did not.": six respondents marked '3'; four students marked '4'; and five students marked '5'. The scale used was 1 = 'I very much disagree' to 5 = 'I very much agree'.

Example quotes from participants who replied with "5":

"[#1] NEET Autonomous Machines prepared me for working in the autonomy field. As an up and coming focus area, I believe I was perceived as a unique candidate in my job search because of my focus on autonomous robotics via NEET in undergrad. I spoke about NEET in job interviews and I feel that it was a strong talking point. I also feel that the skills and knowledge gained from the autonomy-focused coursework has prepared me for modern jobs in the industry. I was able to say that I have already worked on physical robots and autonomy in simulation as a result of my NEET coursework."

"[#4] NEET was great way to expand my professional network and gave me a peer community. Course 7 [Biology] has relatively few undergrads and is not as tight-knit as other majors, so having NEET helped me find support in fellow students."

"[#11] NEET helped me learn to work in a team which has been a very important skill while working. Also being able to communicate your work and ideas is very important and another skill NEET helped me with."

3.2.4. Role models encountered at MIT

Participants were asked "Did you find any role models at NEET? If so, please describe the most influential one or two role models and their career-related impact on you. If you did not find any role models in NEET but did find role models at MIT outside of NEET, then please describe them instead."

12 respondents out of 16 mentioned having encountered at least one role model at MIT. Of those 12, six mentioned having found one or more role models at NEET.

Table 7 summarizes the number of mentions of role models in participants' responses as they reported having encountered at MIT.

Table 7. Role models encountered at MIT.

Role model category	N responses	
	At NEET	*At MIT, non-NEET*
Faculty (research)	2	1
Faculty (instructor)	1	2
Staff (instructor)	2	0
Other students (peers)	2	2

Examples quotes from participants:

“[#1] I found two classes of role models in NEET. One class is the NEET instructors who influenced me to pursue research and grad school. Before joining NEET, I didn't plan on continuing my education beyond my undergrad degree, but I decided to stay at MIT for MEng because of the encouragement of NEET instructors and through learning about their careers. The other class of role models was my peers either in my NEET Autonomous Machines cohort or in the cohort that was older than me. I saw the amazing work they did, and I strove to challenge myself similarly in my coursework, research, and industry experiences.”

“[#10] I appreciated the patience, kindness, and efforts of the technical instructors in NEET and tried to emulate these characteristics when I TA’ed [assisted lecturers in the teaching of] classes later on (specifically, I developed better spoken and written communication skills and collaboration skills).”

“[#12] I can't say that I found any particular role models though NEET, but I did find a number of peers who I really admire. One of my most influential role models that I met while at MIT was my startup co-founder who recruited me to help build the company. He was a senior when I was a freshman [first-year student], and I've always looked up to him in a way. He pushed me to develop skills such as critical thinking, designing, and running experiments, entrepreneurship, learning by oneself, and both spoken and written communication. Along with opening the opportunity to build a company and a new product of my own creation, he was also influential in my decision to pursue a PhD.”

3.2.5. Overall satisfaction with current role

In response to the item “I am satisfied at my current role.”: four respondents marked ‘3’; six students marked ‘4’; and six students marked ‘5’. The scale used was 1 = ‘I very much disagree’ to 5 = ‘I very much agree’.

4. Discussion

4.1. Conclusions

Some indications are already emerging from the preliminary findings. However, since these are descriptive statistics, they should be taken only as initial indications which require further study.

4.1.1. 21st century skill development at MIT

While the mode response for the majority of skills was 4 out of 4 (‘very much’ contributed to development of that skill), a few skills had a different mode response.

‘Entrepreneurship’ had the lowest mode, 2 out of 4 (‘hardly’), ‘formulating questions’ and ‘written communication’ both had a mode of 3 (“moderately”), and ‘engineering design’ and ‘intercultural understanding’ had a mode of 3.5 (in-between ‘moderately’ and ‘very much’).

Notably, three of the five skills with a mode response below 4 were interpersonal skills.

4.1.2. 21st century skill development in experiential learning programs at MIT

When looking only at large gaps between programs (50% or more difference in the number of responses), more participants mentioned NEET over UROP when it came to developing ‘collaboration’, ‘entrepreneurship, ‘engineering design’, ‘spoken communication’, ‘systems thinking’, and ‘written communication’. Four of these six skills are interpersonal.

The only skill for which UROP was mentioned by 50% more participants than NEET was ‘experimenting and testing’, This result is not surprising, as UROP tends to focus in large part on lab-based research work.

The participants appear to be deriving benefits from NEET that are comparable to the 53-year, long-established and highly successful experiential learning program at MIT, i.e., UROP. This should be taken only as an initial indication which requires further data collection and study.

Other experiential learning programs were mentioned by very few participants, and so were not included in this summary.

4.1.3. Unique contribution of program

As further indication of the unique contribution of NEET to students' career readiness, nine of the 16 participants responded with 4 or 5 to the item "My experience in NEET helped prepare me for my career in ways that my other experiences at MIT did not", where 1 = 'I very much disagree' and 5 = 'I very much agree". No participant responded with a '2', and one participant responded with a '1'.

4.1.4. Importance of 21st century skills to career success

The mode response for most skills was 4 out of 4 ('very important' to career success).

However, a few skills had a lower mode response: entrepreneurship had 1.5 (in-between 'not at all' and 'hardly') and 'intercultural understanding' had 3.5 (in-between 'moderately' and 'very'). Both are interpersonal skills.

4.1.5. Career satisfaction

12 of the 16 participants responded with 4 or 5 to the item "I am satisfied in my current role", where 1 = 'I very much disagree' and 5 = 'I very much agree". No participant responded with a '1' or a '2'.

4.1.6. Role models

Overall, more participants mentioned encountering role models at MIT who were related to NEET than role models unrelated to it. Instructors who are staff members (not faculty members) were only mentioned for NEET.

4.2. Discussion of key findings

While this is a work-in-progress, some indications are emerging from the findings thus far. Further study is required to come to definitive conclusions concerning our RQs.

The study's findings that NEET significantly contributes to the development of 21st-century skills, particularly in areas such as collaboration, spoken communication, and engineering design, support the literature's emphasis on the need for education to evolve to prepare students for the modern workforce, as noted in [3,8]. This is crucial because traditional STEM education has often been criticized for not adequately preparing students for real-world, interdisciplinary challenges, emphasizing the need for reform as highlighted by researchers and educational bodies.

Role models can provide encouragement and promote a sense of belonging and self-efficacy for STEM educational attainment, particularly for individuals who feel connected to the role model [12,13]. Role models motivate students by demonstrating that goals are attainable. They are directly involved in an individual’s life, providing encouragement, as well as access to professional information and networks, skills, and social networks [14]. STEM undergraduate students benefited from mentors who cultivated their metacognitive abilities and higher order thinking skills, as seen in [15]. Studies of scientists, physicians, and science and engineering higher education students found that social support, including role models, had promoted their aspirations [16] and achievements [17,18].

The findings related to role models within NEET and the broader university environment echo the theoretical insights which discuss the impact of role models on STEM students: providing students with a sense of belonging and self-efficacy [12,13], encouraging and facilitating their professional aspirations [14-18], and helping to develop their higher-order thinking skills [15].

Since participants overall found more role models within the program than out of the program, we can point to the added benefit that an experiential learning program such as NEET provides students with opportunities to encounter career role models.

The fact that NEET was reported to enhance certain skills (especially interpersonal and domain-agnostic skills) more effectively than UROP does suggests that different experiential learning formats may be suited to developing different skill sets. This aligns with literature suggesting the need for diverse educational approaches to fully equip students for a range of professional challenges [6,7].

The overall positive responses regarding career readiness and satisfaction among participants of NEET suggest that such experiential learning initiatives can play a significant role in enhancing students' perceptions of their preparedness for professional roles. This is particularly relevant given the finding that students’ levels of 21st-century skills do not always correlate with academic achievement [6], underscoring the importance of practical, hands-on experiences in education.

4.3. Limitations and future studies

The sample size (N = 16) did not allow for inferential statistical testing. We therefore could not compare the contribution of NEET versus UROP, compare the contribution of each NEET track, or the differences between gender or race of alumni in statistically significant ways. We plan to continue data collection with current and future alumni of NEET and perform a new, more in-depth analysis of the data once we reach a sample of 20 alumni from each thread, i.e., a total of 40 NEET alumni.

The survey method, while allowing for collecting both quantitative and qualitative data, poses limitations for deep data collection. Interviews and focus groups will allow us to better understand the richness of the experience of students in NEET.

Lastly, the alumni's point of view is not the only relevant one when it comes to the contribution of NEET to its alumni's career readiness. Asking the alumni's employers about their employees' career readiness could help provide another, external perspective without self-bias.

4.4. Contribution of study

By providing empirical data on how participation in an experiential learning program influences the development of 21st-century skills, the study adds quantitative evidence to the discourse on the effectiveness of such programs in STEM education.

The study's comparison between NEET and UROP offers insights into how different experiential learning models contribute uniquely to skill development. This comparative approach helps to delineate the specific contributions of interdisciplinary, project-based learning versus research-based learning.

The research underlines the alignment of educational programs with the evolving needs of the STEM industry. By documenting specific skills that are enhanced through participation in NEET, the study supports ongoing discussions about how universities can adapt their curricula to better prepare students for the demands of modern STEM careers.

Finally, the study also contributes methodologically by using a combination of survey items to provide different perspectives on the development of students' 21st century skills. This provides a template for other educational researchers looking to assess program impacts in a similar context.

A recent white paper [9] described the 'engineer of the future' as someone who has a combination of disciplinary specialization and of cross-disciplinary competencies, calling for a balance between fundamental, generalist courses and courses specialized in emerging specific skills. With NEET, MIT aims to help shift its undergraduate engineering education offering towards such a balance.

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