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Actualization of Integrated STEM Degree Programs: A Model to Inform, Catalyze, and Shape Inter- and Trans-Disciplinary University Education

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Executive Summary

The advent of the Fourth Industrial Revolution (4IR) has catalyzed calls for more integrated education to keep abreast with the changing economic and social needs. Globally, new STEM degree programs have emerged to meet such demands. Yet, few offered an authentic integrated STEM education that underscores the importance of connections between two or more STEM disciplines and aligns to the real demands of 4IR in substantive ways to promote more women in STEM.

The Asia-Pacific Economic Cooperation (APEC) Secretariat, through the Human Resources Development Working Group (HRDWG), had funded this project to develop a model to inform the design, implementation, and assessment of a new integrated and gender-inclusive STEM degree program in APEC economies. Members from the STEM higher education sector in APEC economies were nominated to attend a three-day virtual seminar that was held from 23 to 25 March 2021.

Through the participatory process of engaging in professional dialogues, participants contributed to the pool of knowledge, competencies, and resources supporting the establishment and sustainability of STEM integration. Individual universities may choose to contextualize the findings, recommendations, and the three prototypes that were developed, to their needs. With more and better-quality STEM programs at the university level, it could potentially result in improved quality of human capital to address the demands of the 4IR in STEM and beyond.

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Acronyms

4IR	Fourth Industrial Revolution
APEC	Asia-Pacific Economic Cooperation
APRU	Association of Pacific Rim Universities
FIT	Faculty of Information Technology
HRDWG	Human Resources Development Working Group
IDSF	Interdisciplinary Science Framework
IoT	Internet of Things
MIT	Massachusetts Institute of Technology
NMP	Non-Member Participant
OECD	Organization for Economic Cooperation and Development
PPWE	Policy Partnership on Women and the Economy
STEM	Science, Technology, Engineering, and Mathematics
UNESCO	United Nations Educational, Scientific and Cultural Organization
WISET	Center for Women in Science, Engineering and Technology

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- Dr Paola Magni, Murdoch University (AUS)
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Section 1: Introduction

This report documents the findings and recommendations synthesized from responses gathered through a questionnaire, two diagnostic instruments, and dialogue during a three-day virtual seminar focused on constructing a model for an integrated and gender-inclusive STEM (science, technology, engineering and mathematics) degree program. The outputs of this project would inform the design, implementation, and assessment of STEM degree programs at the University and the employability of the female APEC STEM workforce.

Section 2: Background

STEM education has been advocated by many policymakers as the means to achieve their vocational and economic goals (Williams, 2011). It was also seen as the antidote to global issues, especially those related to the 2030 Sustainable Development Goals (Ng, 2019; UNDP, 2021). An integrative approach to STEM education was deemed necessary to realize the vocational and economic needs laid out by policymakers, provide innovative solutions to global issues, and ensure a good supply of STEM professionals (Sanders, 2009; Blackley & Howell, 2015; Ng, 2019). At the same time, it would address the barriers posed to women who wished to gain authentic STEM experiences in the complex STEM field of the Fourth Industrial Revolution (4IR). Therefore, this project advocates for integrated STEM education as a means to address barriers posed to women who wish to gain authentic STEM experiences in the complex STEM field of the 4IR, characterized by disruptive technologies such as the Internet of Things, robotics, virtual reality, and artificial intelligence. Women can contribute additional perspectives and new worldviews to innovations in 4IR and benefit economically to raise their standards of living (Nathan Associates, 2016).

Universities play a significant role in the supply of a trained workforce, in particular, STEM professionals equipped with the knowledge and skills to accelerate innovations and push frontiers in STEM. As such, it is important to offer degree programs that better prepare graduates with relevant knowledge, skills, and attitudes to take on the evolving expectations of STEM workplaces. Given the versatility of STEM fields, it is important for both genders to be represented to enrich the diversity of the field, and address different expectations and needs of STEM consumers, including users of STEM innovation products, and citizens who need to make informed decisions concerning their lives by applying relevant STEM information.

However, STEM integration had much less presence at the university level, as compared to K-12 education (Asunda, 2014). A scan of University programs named “STEM” in 2018 revealed a dearth of degree programs that offer a truly *integrated* STEM education for learners and also empower women to participate as full members of the STEM arena in working to solve real world problems requiring the application of more than one field of knowledge. It is evident from the course titles and outlines that university STEM degree programs tend to be mono-disciplinary with limited or no explicit connections between two or more of the STEM disciplines.

Furthermore, women continued to be marginalized in several STEM fields (Van Tuijl & Van der Molen, 2016). The UNESCO Institute for Statistics (2021) estimated that women constituted only 29.3 percent of scientific researchers worldwide. As a result, the number of women holding senior management positions in STEM remained low (UNESCO, 2016). This presented a missed opportunity for STEM since women could bring in “a different perspective that shapes and influences STEM disciplines” (Milgram, 2011: 5).

Mono-disciplinarity is typically associated with: (1) positivist and singular mindsets; (2) the acceptance of one best answer; (3) prioritizing methods that are linear, systematic, and rigorous; (4) valuing of objectivity; and (5) generalization of findings. On the other hand, gender-inclusive approaches value: (1) critical and transformative mindsets; (2) multiplistic understandings and co-creation of shared meanings; (3) methods that engages different viewpoints and voices; (4) valuing of reasoning, emotions, experiences, biases, and relationships; (5) acknowledging that knowledge is complex and partial; and (6) contextualizing findings (Maher, 1985).

In 2021, the phenomena continued to persist as alluded by the participants at the seminar. Whilst 85 percent of the respondents in the pre-seminar questionnaire shared that there were STEM programs in their economies, only 37 percent of them were integrative. Two possible reasons for the lack of real STEM integration in university programs include: (1) the existence of structural constraints in inter-departmental/college collaborations, and (2) the lack of a deep understanding of STEM curriculum integration among faculty members residing in traditionally separate colleges. As such, STEM integration has much less presence at the university levels as compared to K-12 education (Moore & Smith, 2014).

Possible reasons for the poor female representation in higher education context include: (1) the view that the inclusion of women is irrelevant as STEM subjects comprise cold-hard facts; (2) there are few women in position to promote change in the disciplines and hence, less vested interest in changing the status quo; (3) STEM experts do not usually have the training to consider social factors that shape their field as they see STEM as a fair competitive ground; and (4) STEM university faculty whose studies focus on women's lives must engage in cross-institutional work and hence, may invite criticism from colleagues and institutions (Blickenstaff, 2005).

The three-day virtual seminar that was held from 23 to 25 March 2021 was a crucial component of this project. It focused on the construction of a model for an integrated and gender-inclusive STEM program. 32 participants from 11 economies were present at the seminar. They comprised 16 nominees and 16 non-member participants (NMP) from the STEM higher education sector in 11 economies (see Table 2-1).

APEC Economy	Nominees from APEC Economies	Non-Member Participants (NMP)	Total
AUS	6	0	6
BD	2	0	2
HKC	0	2	2
INA	1	0	1
MAS	0	5	5
MEX	1	0	1
PH	1	0	1
ROK	2	1	4
RUS	1	0	1
SGP	2	7	9
USA	0	1	1
	16	***16 (included 9 facilitators and 3 keynote speakers)***	***32***

Table 2-1 Breakdown of representations from 11 APEC economies at the three-day virtual seminar

The 16 nominees were largely university faculty (e.g., professors, associate professors, lecturers from STEM and STEM education). The 16 NMP included three keynote speakers, nine staff from the Project Overseers' universities who facilitated the breakout sessions, and representatives from the Association of Pacific Rim Universities (APRU). The male-female gender ratio of the 32 participants was 11:21. A detailed list of all the participants – nominees and NMP – is found in Appendix 1. In addition to the 32 nominees and NMP (collectively referred to as "Participants" in this report), the seminar was also attended by two representatives from APEC.

The findings and recommendations in this report were gathered from:

a. Participants' responses to the pre-seminar questionnaire (a sample copy of the questionnaire is enclosed in Appendix 2);
b. Presentations and breakout session discussions during the three-day seminar on four topics: (i) STEM integration, (ii) gender inclusivity, (iii) curriculum model, and (iv) develop an integrated and gender-inclusive STEM course; and
c. Participants' responses to the pre-and post-seminar diagnostic surveys to track the changes in participants' knowledge (a sample copy of the survey and data collected has been included in Appendix 5a and 5b).

2.1 Pre-Seminar Questionnaire

The objective of the pre-seminar questionnaire was to obtain baseline information about the status of STEM education at higher education in the APEC economies. Although the responses collected could not be representative of all the universities in the respective economy, they afforded insights into the variety of STEM programs and efforts to promote integrated STEM education and STEM education for women.

The questions focused on the existing STEM degree programs and events at the universities, plans for an integrated STEM degree program in the next five years, and how the participants would envision a new integrated STEM degree program. A total of 26 responses were collected, attaining a response rate of 81 percent (N=32). Selected key findings were elaborated below:

(i) Lack of Integrated STEM Degree Programs

85 percent of the respondents (N = 26) shared that there were STEM degree programs in their economy. Among these STEM degree programs, 42 percent were offered at the undergraduate level, 32.5 percent were offered at the Master's level, and 25 percent were offered at the Ph.D. levels. These programs were largely mono-disciplinary meaning that it had a focus on one of the STEM disciplines. Only 37 percent of the degree programs were integrated STEM (i.e. at least two or more of the STEM disciplines).

(ii) Emergence of Interdisciplinary and Women-Specific STEM Programs

Several interdisciplinary degree programs were offered at the undergraduate and graduate levels (see Table 2-2). There were also elective programs within the degree programs specifically designed to promote more women in STEM.

Interdisciplinary STEM Degree Programs

- Agricultural Technology
- Architecture & Design
- Bachelor of Applied Data Analytics
- Bachelor of Mathematical and Computer Sciences
- Bachelor of Mathematical Science
- Bachelor of Science in Integrative Systems and Design (ISD)
- Bachelor of Science (Mineral Geoscience)
- Bachelor of Science (Space Science and Astrophysics)
- Bachelor of Science (Veterinary Bioscience)
- Bachelor of Science (Wildlife Conservation Biology)
- Bachelor of Veterinary Technology,
- Bachelor and Masters of Viticulture and Oenology
- Bioinformatics and Genomic
- Faculty of Science and Data Analytics
- Faculty of Industrial Technology and System Engineering
- Faculty of Intelligent Electrical and Informatics Technology
- Faculty of Civil, Planning, and Geo Engineering
- Food Science & Technology
- Master in Theories and Technologies of STEM Education
- Science Information Technology

Elective STEM Programs For Women

- WINE (Woman IN Engineering) Program
- WIC (WINE Intensive Course) Division of Convergence

Table 2-2 List of interdisciplinary degree programs and elective STEM Programs designed for women

(iii) Critical Success Factors in Designing an Integrated STEM Program

The critical success factors in designing an integrated STEM program could be classified into four broad categories, namely curriculum design, institutional leadership, instructors, and students.

A successful integrated STEM program should be student-centered and adopt a non-linear design approach. It was also important for curriculum designers to agree on a set of knowledge and skills that were critical across STEM before they start designing a new STEM program.

STEM degree programs should include inclusive projects with social impact, discuss problems that were personally relevant to the student and promote diverse gender perspectives. Having cross-disciplinary courses and practices would allow students to transfer their disciplinary knowledge into other areas of inquiry. While research was a common feature of degree programs, it should be introduced earlier in an undergraduate program. Authentic assessments that aligned with the objective of the program ought to be considered too.

Concerns about the lack of resource support for cross-disciplinary programs were raised. It was suggested that university administrators should allow faculty members to flexibly engage in cross-departmental work and give due recognition of their work beyond the primary discipline.

For university instructors to deliver an integrated STEM program effectively, they may need to undergo continual training in evidence-based and student-centered pedagogical practices.

Such professional development could be included as part of the university instructors' teaching and service rather than as additional workload.

Whilst the university leaders and instructors could be well-prepared to mount a new integrated STEM degree program, students must possess the proper skill and attitude to engage in independent and collaborative learning.

(iv) Measures of Success

The success of their STEM programs could be measured using one or more of these indicators:

a. Accreditation by external bodies;
b. Level of integration across disciplines;
c. Number of graduates;
d. Positive feedback from students; and
e. The extent of interdepartmental collaboration during course delivery.

(v) The Design of Gender Inclusivity in STEM Programs

Two views about gender inclusivity in existing STEM degree programs at the respondents' universities were illuminated:

a. There was gender inclusivity because there were no explicit structures (e.g., rules) to exclude females or males from a program, it was not visibly present, and it was not a topic that was discussed.
b. There was gender discrimination because there were explicit efforts to address this issue. For example, female role models in STEM were identified and there were institutional policies to deal with issues such as sexual harassment.

2.2 Overview of the Three-Day Seminar

To set the context for in-depth discussion on the three key topics of this project, the participants were invited to watch two interview videos of STEM professionals before the seminar. Three keynote presentations were also planned around the three topics to ensure that the participants shared a common understanding of the terms STEM and gender inclusivity before conceptualizing a prototype of an integrated STEM degree program that also addresses gender inclusivity. Below is a list of the keynote speakers and the title of their presentations:

a. STEM Integration Models by Dr Lilia Halim, The National University of Malaysia (MAS),
b. The Need for Gender-Inclusive STEM Education by Dr Sonya N. Martin, Seoul National University (ROK), and
c. Curriculum Models for STEM by Dr Yew Jin Lee, National Institute of Education, Nanyang Technological University (SGP).

The content of their presentations was drawn from the literature as well as their own research. A short biography of each keynote speaker could be found in Appendix 3. A set of their presentation slides were also included in the Appendix 6, 7 and 8.

After each keynote presentation, the participants took part in a dialogue in three parallel breakout sessions. The discussions were managed by pre-assigned group facilitators (faculty members or staff from the Project Overseers' universities) who acted as the moderator or scribe. A set of pre-determined questions were used to guide the group discussion. These questions, closely aligned to the content of the keynote presentations, were co-developed by the keynote speakers and Project Overseers. The purpose of the breakout sessions was to gather the participants' inputs on the topics presented at these keynote sessions. As part of their capacity building, the breakout sessions afforded a platform for them to have dialogue with participants from other APEC economies, synthesize the information by applying it to their own contexts, and learn from one another.

Following each breakout session, a participant from each breakout group presented the key points of the group discussion to all the participants. This allowed other participants to broaden their perspectives. On the last day of the seminar, the participants were tasked to develop a prototype of an integrated and gender-inclusive STEM course.

The seminar ended with the sharing of case study examples by three participants who were invited speakers:

a. Pedagogies adopted for enacting integrated STEM courses by Dr Gillan Kidman, Monash University (AUS) and Dr Aik-Ling Tan, National Institute of Education, Nanyang Technological University (SGP), and
b. Gender-inclusive assessment for integrated STEM tasks by Dr Paola Magni, Murdoch University (AUS).

A copy of the seminar agenda can be found in Appendix 4.

2.3 Pre-and Post-Seminar Diagnostic Surveys

A diagnostic survey was administered on the first and last day of the seminar to ascertain the changes in the participants' knowledge about: (a) STEM integration, (b) gender inclusivity, and (c) curriculum models. 15 (47 percent) and 9 (28 percent) responses were received (N = 32) for the pre-and post-seminar diagnostic surveys respectively. The rest of this section would attempt to highlight the key changes on comparing the pre-and post-seminar diagnostic surveys. A complete set of questions and data collected from the surveys are enclosed in Appendix 5a and 5b.

(i) Increased confidence in implementing an integrated and gender-inclusive STEM program

The respondents were asked to rate on a five-point Likert scale (1=Strongly Disagree; 5=Strongly Agree), their extent of agreement to a set of statements about Integrated STEM Education. A comparison of the mean scores from the pre-and post-seminar diagnostic surveys showed an increase from 4.06 to 4.57 (see Table 2-3). This is the highest recorded mean score gain for the entire survey. With a high rating of 4 and above recorded for most of these statements in the pre-seminar diagnostic survey, it indicated that the majority of the participants at the seminar were able to influence changes in curriculum design at their universities, By the end of the seminar, they reported greater understanding of the challenges in planning an integrated STEM program. They were also more confident in infusing gender inclusivity in the STEM programs at their universities.

#	Q2. Please respond to the following items:	Mean Pre	Mean Post	Std Pre	Std Post
	I know the purpose(s) of an undergraduate STEM education.	4.40 *(N=15)*	4.67 *(N=9)*	0.71 *(N=15)*	0.47 *(N=9)*
2	What we plan for STEM education will make the economy a better place.	4.53 *(N=15)*	4.67 *(N=9)*	0.62 *(N=15)*	0.47 *(N=9)*
3	What we plan for STEM education will make the Universities a better place.	4.53 *(N=15)*	4.67 *(N=9)*	0.62 *(N=15)*	0.47 *(N=9)*
4	I have thought about how my gender can influence my curriculum making.	3.93 *(N=15)*	3.89 *(N=9)*	1.00 *(N=15)*	1.20 *(N=9)*
5	I have thought about how my experiences, can influence my curriculum making.	4.20 *(N=15)*	4.89 *(N=9)*	0.65 *(N=15)*	0.31 *(N=9)*
6	I have thought about how my training can influence my curriculum making.	4.27 *(N=15)*	4.89 *(N=9)*	0.68 *(N=15)*	0.31 *(N=9)*
7	I know the challenges in planning an integrated STEM degree program.	3.93 *(N=15)*	4.67 *(N=9)*	0.85 *(N=15)*	0.47 *(N=9)*
8	I know the challenges in planning a gender inclusive STEM degree program.	3.60 *(N=15)*	4.56 *(N=9)*	0.95 *(N=15)*	0.68 *(N=9)*
9	I am confident of implementing a gender inclusive STEM degree program.	3.47 *(N=15)*	4.44 *(N=9)*	0.88 *(N=15)*	0.68 *(N=9)*
10	I am confident of implementing an integrated STEM degree program.	3.73 *(N=15)*	4.33 *(N=9)*	1.00 *(N=15)*	0.67 *(N=9)*
	Overall Mean	***4.06***	***4.57***		
	Overall Standard Deviation			***0.80***	***0.57***

Table 2-3 Participants' responses to statements on Integrated STEM Integration in the pre-and post-seminar diagnostic surveys

(ii) New understanding of an integrated STEM education

Based on the responses to Question 4, the following ideas that were not previously mentioned in the pre-seminar diagnostic survey were revealed in the post-seminar diagnostic survey:

a. There are multiple learning and teaching pathways in STEM. The problem/issue used must be functional, transferable, and expandable (something that can evolve in time) to the students.
b. Other than using real-world problems in STEM lessons, these problems should also possess characteristics of reflexivity, flexibility, and gender inclusivity. There must be a compelling reason for students to solve these problems. This could be achieved by connecting the problem to the community of the students.
c. While non-integrated STEM could take on a progressively linear approach to education, integrated STEM education adopts a non-linear approach right at the beginning of the educational process.
d. Students should be assigned the responsibility of connecting the STEM content in an integrated lesson.

(iii) Individual pride and societal beliefs could hinder the implementation of an integrated STEM program

The responses gathered from Question 8 suggested that university instructors have "Too much pride in one's discipline" (the highest percentage gain of 3.18 as compared with the other challenges listed) and this could pose as a barrier to the successful implementation of an integrated STEM program (see Table 2-4).

#	**Q8 - Which of the following are possible challenges to successful implementation of an integrated STEM curriculum at the University? (You may select more than 1.)** **Answer**	**Pre**	**Post**
1	Lack of collaboration across departments or colleges	21.54%	16.28%
2	Resistance from faculty members	13.85%	13.95%
3	Too much pride in one's discipline and training	10.77%	13.95%
4	Lack of structures (e.g.,, policies on collaboration, recognition, rewards, etc.)	20.00%	20.93%
5	Insufficient resources for integrative work	15.38%	16.28%
6	Lack of knowledge of STEM integration among faculty members	18.46%	18.60%
	Total	***100%***	***100%***

Table 2-4 Participants' responses to Question 8 – Which of the following are possible challenges to successful implementation of an integrated STEM curriculum at the University? (You may select more than 1.) - in the pre-and post-seminar diagnostic survey

Social perception of an integrated degree program could be another barrier. One respondent expressed doubts on the employability of an integrated STEM degree graduate: "A double degree is recognized, but not an integrated degree. Societal views need addressing…. [the] industry not realizing the graduate's potential (Post-diagnostic survey respondent, 25 Mar 2021). This suggests that University leaders could engage in active communication with the industries, to understand the knowledge and skills that they would want the graduates to have, and allow them to understand what students are learning, and how they are trained in the universities.

(iv) Characteristics of a STEM educator

By the end of the seminar, it was generally agreed that as compared to a science, mathematics, engineering, or technology educator, a STEM educator is more competent in the following areas (these items registered an increase in percentage score in the post-seminar diagnostic survey):

a. Equipped with more diverse teaching strategies
b. A team player
c. More adaptable
d. Has deeper content knowledge of the discipline(s)
e. Address diverse students' needs
f. More open to different perspectives
g. Has stronger pedagogical knowledge
h. Is Future-Ready
i. Able to integrate different disciplinary ideas
j. More flexible in problem solving

However, they thought that a STEM educator might not necessarily be better at solving more complex problems or had broader content knowledge of the various disciplines (See Table 2-5).

#	Q10 - In comparison to a science, mathematics, engineering, or technology educator, a STEM educator is better in the following aspects:	Mean Pre	Mean Post	Std Pre	Std Post
1	Able to solve more complex problems	4.20 *(N=15)*	3.89 *(N=9)*	0.98 *(N=15)*	1.10 *(N=9)*
2	Equipped with more diverse teaching strategies	4.00 *(N=15)*	4.22 *(N=9)*	0.97 *(N=15)*	0.92 *(N=9)*
3	A team player	3.87 *(N=15)*	4.22 *(N=9)*	0.88 *(N=15)*	0.92 *(N=9)*
4	More adaptable	4.07 *(N=15)*	4.44 *(N=9)*	0.93 *(N=15)*	0.96 *(N=9)*
5	Has deeper content knowledge of the discipline(s)	3.00 *(N=15)*	3.33 *(N=9)*	0.89 *(N=15)*	1.05 *(N=9)*
6	Has broader content knowledge of the discipline(s)	3.93 *(N=15)*	3.78 *(N=9)*	0.77 *(N=15)*	1.13 *(N=9)*
7	Address diverse students' needs	3.80 *(N=15)*	4.22 *(N=9)*	0.91 *(N=15)*	0.92 *(N=9)*
8	More open to different perspectives	4.07 *(N=15)*	4.22 *(N=9)*	0.77 *(N=15)*	0.92 *(N=9)*
9	Has stronger pedagogical knowledge	3.80 *(N=15)*	4.22 *(N=9)*	0.91 *(N=15)*	0.92 *(N=9)*
10	Is Future-Ready	3.93 *(N=15)*	4.22 *(N=9)*	0.85 *(N=15)*	0.92 *(N=9)*
11	Able to integrate different disciplinary ideas	4.29 *(N=14)*	4.33 *(N=9)*	0.80 *(N=14)*	0.94 *(N=9)*
12	More flexible in problem solving	4.21 *(N=14)*	4.44 *(N=9)*	0.86 *(N=15)*	0.96 *(N=9)*
	Overall Mean	***3.93***	***4.13***		
	Overall Standard Deviation			***0.88***	***0.97***

Table 2-5 Participants' responses to Question 10 – In comparison to a science, mathematics, engineering, or technology educator, a STEM educator is better in the following aspects - in the pre- and post-seminar diagnostic surveys

(v) Gender inclusivity goes beyond increasing the number of females in STEM education

There was general agreement that having a gender-inclusive STEM program does not necessarily mean having more female students or female faculty members. Instead, infusing inclusivity by making changes to the curriculum design, selecting appropriate pedagogies and having both male and female role models to make the environment more gender-friendly (see Table 2-6) were preferred. The respondents also expressed greater confidence in teaching gender inclusivity at the end of the seminar[1].

[1] Refer to Appendix 5b Question 12.

#	Q11 - STEM programs can be more gender inclusive by:	Mean Pre	Mean Post	Std Pre	Std Post
1	Enrolling more female than male students	3.71 *(N=14)*	3.63 *(N=9)*	1.03 *(N=14)*	0.99 *(N=9)*
2	Creating more team based activities	4.36 *(N=14)*	4.44 *(N=9)*	0.61 *(N=14)*	0.50 *(N=9)*
3	Adopt more participatory approaches	4.50 *(N=14)*	4.67 *(N=9)*	0.50 *(N=14)*	0.47 *(N=9)*
4	Creating more open-ended than close-ended test items	4.21 *(N=14)*	4.44 *(N=9)*	0.77 *(N=14)*	0.50 *(N=9)*
5	Arrange for more project work	4.07 *(N=14)*	4.22 *(N=9)*	0.80 *(N=14)*	0.63 *(N=9)*
6	Creating problems just for female students	2.50 *(N=14)*	2.78 *(N=9)*	0.91 *(N=14)*	0.63 *(N=9)*
7	Hiring more female STEM faculty	4.21 *(N=14)*	4.11 *(N=9)*	0.77 *(N=14)*	0.74 *(N=9)*
8	Assign female STEM faculty as mentor to each female student	3.71 *(N=14)*	4.22 *(N=9)*	0.70 *(N=14)*	0.79 *(N=9)*
9	Create flexible degree programs	4.07 *(N=14)*	4.56 *(N=9)*	0.70 *(N=14)*	0.50 *(N=9)*
10	Offering elective courses that explicitly address gender issues	3.79 *(N=14)*	4.00 *(N=9)*	0.86 *(N=14)*	0.47 *(N=9)*
11	Offering compulsory courses that explicitly address gender issues	3.43 *(N=14)*	3.56 *(N=9)*	0.90 *(N=14)*	1.26 *(N=9)*
12	Foregrounding women's needs in solving STEM problems	4.07 *(N=14)*	4.22 *(N=9)*	0.70 *(N=14)*	0.63 *(N=9)*
13	Having male and female role models	3.77 *(N=13)*	4.44 *(N=9)*	1.12 *(N=13)*	0.68 *(N=9)*
	Overall Mean	***3.88***	***4.10***		
	Overall Standard Deviation			***0.80***	***0.68***

Table 2-6 Participants' responses to statements on Gender Inclusivity in the pre-and post-seminar diagnostic surveys

Section 3: STEM Integration

Although the world demanded for a greater number of graduates trained in STEM, Dr Lilia Halim observed that STEM integration was largely absent at the university level. According to Asunda (2014), current programs that have a STEM focus are discipline-specific and fall into one of these categories:

> (a) a concentration on developing a greater depth of content knowledge in a single STEM field (e.g., chemistry, mathematics, physics, electrical engineering); (b) an emphasis on a particular STEM education discipline (e.g., mathematics education, science education, technology and engineering education) and offers a mix of discipline-specific research, pedagogy, and content courses; or (c) a focus which is more cross-disciplinary, requiring participants to enroll in a set of core education and research courses and to select a mixed collection of elective courses from a list of STEM-related disciplines across campus (e.g., biology, geology, mathematics). (p. 5)

3.1 Lack of Integrated STEM Programs at University Level

Possible reasons for the lack of real STEM integration in university programs include the structural constraints in inter-departmental/college collaborations, the lack of funds, reward and insufficient deep understanding of STEM curriculum integration among university instructors working in traditionally separate colleges.

(i) Structural Constraints in Inter-Departmental/College Collaborations

Williams (2011) warned that the “rigidity and resilience of the school curriculum structure” (p. 27) could undermine the implementation of an integrated STEM program. This rigidity and resilience were referred to as the “grammar of schooling” (Tyack & Tobin, 1994).

Such structural constraints made it challenging to introduce any integrative programs. A participant shared his experiences with the four interdisciplinary courses that he convened at his university. He professed that it was challenging for his courses to gain traction due to two reasons: (a) students might have interests in these courses but the curriculum was too packed and they were not able to take on more classes, and (b) since these courses were not owned by any of the colleges in the university, it did not ‘belong’ anywhere. Nevertheless, if these courses were offered by the Department/College/Faculty of Science, they would be regarded as science courses and lose the interdisciplinary flavor.

(ii) Funding

In Dr Lilia Halim’s keynote presentation, she remarked about the lack of funding sources that support integration work. This point was raised several times during the breakout session discussions. It was underscored that the lack of funds was a key obstacle to the implementation of an integrated STEM program.

It was suggested that an expansion of funding sources to include government agencies, industry partners, and philanthropists would be beneficial in supporting integrated STEM work. It might also be worthwhile to reposition these programs under the category of teaching and/or learning innovations. Having a pilot program could help to convince potential funders about the benefits of these integrated STEM programs. Publicizing the positive feedback from students who had participated in these programs and emphasizing the achievements of other similar programs to the alumni, university administrators, and in news media are possible means to create more awareness and generate stronger funding support.

When pitching for support in inter-or transdisciplinary work from their university leaders, faculty members are leveraging on their expert knowledge to engage in inter-collegial human capacity building. One participant shared that cross-collaboration between faculties and team teaching were common at her university. She said, “I am from Education faculty, but I have taught in Science and Engineering faculty courses to improve the teaching strategies and thus, learning”.

(iii) Lack of Reward and Recognition

It was widely agreed that the increased workload and time associated with planning a new integrated STEM degree program may not be rewarding. It was possible that cross-disciplinary, as compared to specialization work is not valued and hence, not considered favourably during the faculty tenure and promotion exercise. Such work was perceived as a dilution, rather than deepening of one’s expertise. Hence, faculty members remained loyal to their discipline and were not motivated to undertake cross-disciplinary work.

Most universities did not have a structure that allowed faculty members to count the time spent on program design toward the teaching hours that they need to fulfill, especially when the program went beyond one's discipline. To push for more integrated STEM degree programs, it was therefore important to have policies at university level that support and recognize university instructors for their contributions to these programs.

(iv) Inadequate Manpower

Inadequate administrative support, mentoring, and university instructors with relevant knowledge to design or teach integrated STEM degree programs were cited as possible constraints. A supportive culture for implementing an innovative curriculum could be possible if there were student assistants and mentors with knowledge about the field. A strategic task force led by a key university administrator could be set up to show support and commitment for integrated STEM education work.

Since most senior university instructors were discipline-based, it may be difficult to pair them with junior university instructors who would like to pursue integrated STEM education. This could be resolved by having a few senior university instructors as mentors to one junior university instructor. The universities could explore co-teaching and collaboration of university instructors or even with graduate students, from across disciplines.

3.2 STEM Integration Models

Existing integrated STEM degree programs at the universities generally adopt inter-and transdisciplinary forms of integration. Three STEM integration models that could be applied in curriculum design were presented in Dr Lilia Halim's keynote talk. The models included the STEM integration matrix by English (2017), a model that focused on transdiciplinary skills by Tan *et al.* (2018), and the Interdisciplinary Science Framework (IDSF) by Tripp and Shortlidge (2019).

(i) STEM Integration Matrix

Coined by English (2017), the STEM integration matrix, integrated activities were categorized based on content or context. In an example that was given, a problem was designed with mathematics and engineering forming the primary content areas, and science as the supporting content. Engineering and technology provided the disciplinary contexts for integration, while societal and historical issues offered the background context for integration.

(ii) Focus on Transdisciplinary Skills

Tan *et. al* (2018) argued that a transdisciplinary curriculum must equip students with empathy, systems thinking, and metacognitive skills. Systems thinking is a core competency that involved the "ability to connect the practical to the theoretical, and one level of a problem with multiple levels of the same problem", whereas empathic perspective-taking enabled students to develop a deep understanding and care for the concerns and needs of stakeholders (Orozco-Messana *et al.*, 2020: 4). Such empathy, in turn, would stimulate "ethical decision-making and human-centered design" (Tan *et al.*, 2018: 2). Metacognition also played an important role in transdisciplinary interactions by empowering individuals to "monitor, reflect on, and adapt learning processes in a multidimensional context" (Orozco-Messana *et al.*, 2020: 4).

In 2016, a research-intensive university in Midwest, USA, introduced two Bachelor's degrees that focused on transdisciplinary and competency-based education – Bachelor of Science (B.S.) in Transdisciplinary Studies in Technology (BS-TST), and B.S. in Transdisciplinary Studies in Engineering Technology (BS-TSET) (Bosman & Duval-Couetil, 2019). Table 3-1 gives an overview of how the credit system was structured in these programs:

S/No.	Components	No. of Credits Required	B.S. in Transdisciplinary Studies in Technology (BS-TST)	B.S. in Transdisciplinary Studies in Engineering Technology (BS-TSET)
1	General Education Credits	40	✓	✓
2	Core Credits	40	✓ (Compulsory courses: Design-Studio and ePortfolio)	✓ (Compulsory courses: Design-Studio and ePortfolio)
3	Free Credits	40	✓ (Courses offered in the university)	✓ (Courses offered by School of Engineering Technology)
	Total No. of Credits	***120***		

Table 3-1 Credit structure of B.S. in Transdisciplinary Studies in Technology (BS-TST), and B.S. in Transdisciplinary Studies in Engineering Technology (BS-TSET) (Bosman & Duval-Couetil, 2019)

In giving students access to courses beyond their home departments/colleges, students could integrate a variety of disciplines from "humanities to technology and approach problem-solving from a more holistic and human-centered perspective" (Bosman & Duval-Couetil, 2019: 4). Furthermore, students gained competency skills in six cluster areas: (a) create and innovate, (b) interact with others, (c) inquire and analyze, (d) engage in culture, values, and the arts, and (e) communicate (see Table 3-2).

Competency Cluster	Individual Competency
Create and innovate	Systems Thinking
	Design Thinking
	Problem Scoping
	Entrepreneurial thinking
Interact with others	Individual Contribution
	Give, Receive, and Act on Critique
	Leadership
	Emotional Intelligence
	Active Listening
Inquire and analyze	Critical Thinking
	Quantitative Reasoning
	Qualitative Reasoning
	Information Literacy
Engage in culture, values and the arts	Cultural Engagement
	Arts Engagement
	Ethical Engagement
Communicate	Written Communication
	Oral Communication
	Visual Communication
	Integrated Communication

Table 3-2 Competency clusters in BS-TST and BS-TSET (Bosman & Duval-Couetil, 2019)

The seminar participants were generally supportive of this approach in curriculum design. Other soft skills such as problem-solving, communication, digital literacy were ranked by them as the three most important knowledge and skills that should be incorporated in an integrated STEM program.

(iii) Interdisciplinary Science Framework (IDSF)

Interdisciplinarity was another widely researched approach to integrated STEM education and could potentially develop students to solve complex, real-world problems. Tripp and Shortlidge (2019) proposed an Interdisciplinary Science Framework (IDSF) to guide curriculum designers in the development and assessment of interdisciplinary efforts in undergraduate science education. This framework entails: (a) disciplinary grounding, (b) disciplinary humility[2], (c) different research methods, (d) collaboration across disciplines and (e) advancement through integration.

Under IDSF, students from STEM and non-STEM disciplines could leverage on one another's disciplinary expertise to frame the problem (disciplinary grounding). They must have a disciplinary humility mindset to explore and become familiar with the other disciplines outside their major. With the knowledge of the different research methods, and their familiarity with the content, perspectives and research methods of the other disciplines, students would be able to work collaboratively across disciplines and advance the solution beyond the capability of one discipline alone (advancement through integration).

A typical classroom lesson using the IDSF framework would involve the following steps:

a. Students would be placed in teams and tasked to identify the disciplines that might be involved in solving the problem.
b. While working in teams, students would be assigned to research into the problem from one of the disciplines identified in (a).
c. Students would independently research on the discipline that they were assigned to and discover how these disciplines were related to the problem.
d. Students would reconvene to collaboratively discuss relevant disciplinary content, identify and explain the research methods, and uncover the limitations of their disciplinary role.
e. Students would then collectively decide on how each discipline and method(s) could be leveraged and integrated to form a solution.

To assess students' learning, they could be asked to submit a worksheet containing questions that were related to the problem. Other assessment examples included quizzes and/or exam questions and written assignments (e.g., essay, proposal and research paper). These assessment methods would enable instructors to assess the extent to which they have met the learning goals (Tripp & Shortlidge, 2019).

3.3 Pedagogies for Integrated STEM Programs

[2] Disciplinary humility is a "mindset, or epistemic perspective, that is infused with humility, inclusivity, and respect for other disciplinary epistemologies" (Tripp & Shortlidge, 2019: 5).

Dr Gillan Kidman (AUS) and Dr Aik-Ling Tan (SGP) were invited to share on pedagogies used in the delivery of integrated STEM courses in Australia and Singapore, respectively. The case examples presented were:

a. FIT3146 Maker Lab, a university course at the Monash University (Monash University, 2019), and
b. The S-T-E-M Quartet instructional framework (Tan *et al.*, 2019).

(i) FIT3146 Maker Lab

Offered to third-year students in the Faculty of Information Technology (FIT), FIT3146 Maker Lab course aimed to develop specific process skills that were lacking in FIT students, but were critical for them to thrive in the workforce. Due to its popularity, FIT3146 is now open to students from other faculties.

Dr Kirsten Ellis, the course designer, had planned for students to develop teamwork or management skills, professionalism, create solutions to problems, and become more resilient (i.e. by being able to work through failure). These course objectives were realized by:

a. Placing a focus on learning
b. Focusing on a problem
c. Emphasizing on open-ended and hands-on learning
d. Using variable assessment
e. Using questions to trigger students' thinking
f. Giving students the autonomy over the choice of their project
g. Engaging teamwork and collaboration as the primary instructional approaches

Notably, it was important for ground rules and expectations to be communicated to students at the start of the course. For instance, social loafing and plagiarism were not allowed. Students were told that they would be assessed on their skills and attitudes, and not on content knowledge alone.

Dr Gillian Kidman observed that more than one pedagogy was enacted during the course. Depending on the problem that the students were working on, the pedagogies could evolve from inquiry-based learning, project-based learning, to problem-based learning. There were very few problems that progressed into challenge-based learning. The choice of pedagogies could change as the curriculum progressed. Figure 3-1 provides a summary of the pedagogies used in the course - FIT3146 Maker Lab.

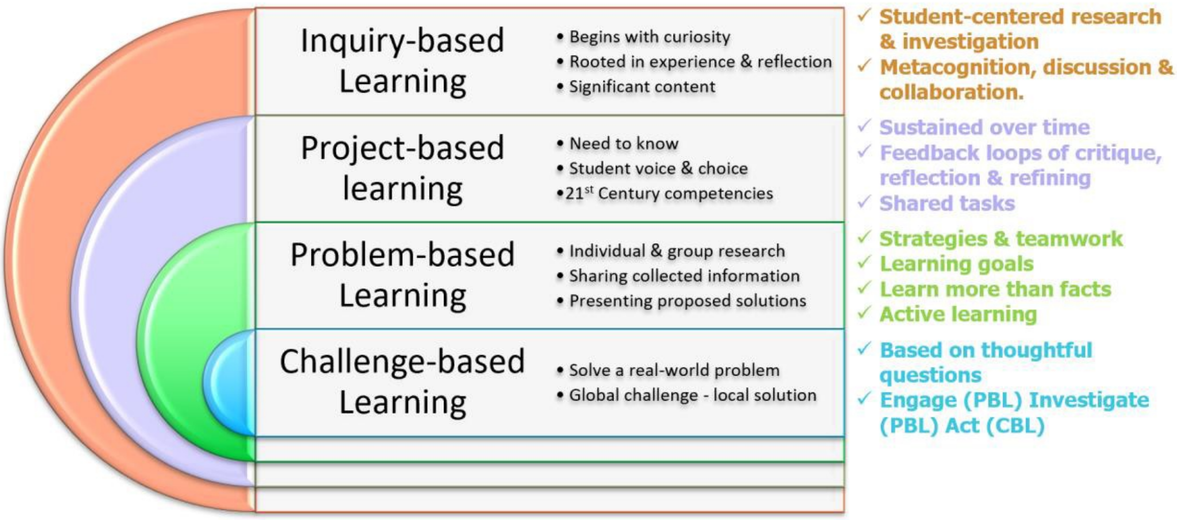


Figure 3- 1 Pedagogical summary of FIT3146 Maker Lab at Monash University (AUS) (© do not cite without permission from Gillian Kidman Monash University, Australia)

(ii) S-T-E-M Quartet Instructional Framework

The S-T-E-M Quartet instructional framework (Tan *et al.*, 2019) was created to help K-12 teachers plan integrated STEM lessons. The focus was on three areas: (a) to engage students in deep disciplinary learning, (b) to make meaningful connections across disciplines and (c) to use problems as the integrative mechanism. The thickness of the connecting lines between disciplines, as shown in Figure 3-2, denoted the presence of strong, moderate, and weak connections between the four disciplines.

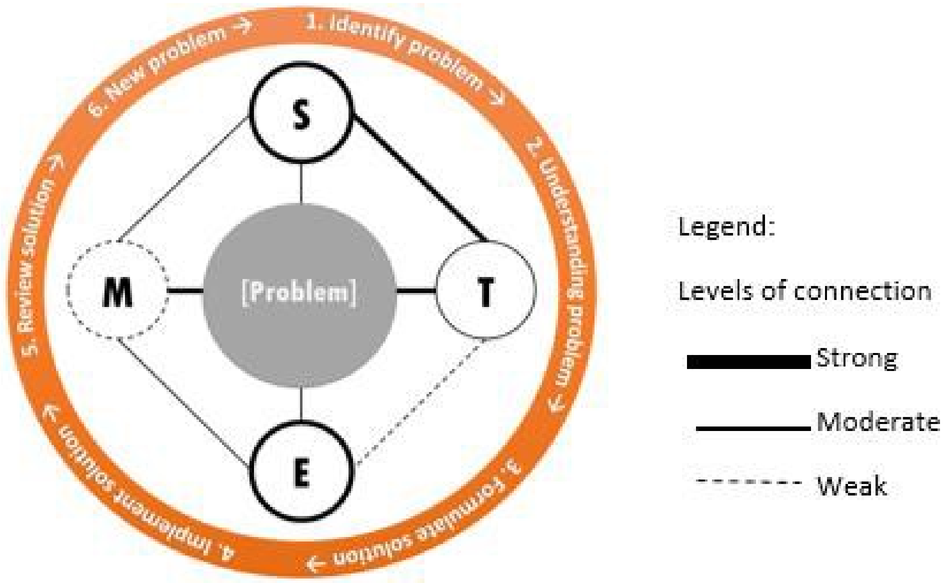


Figure 3-2 S-T-E-M Quartet instructional framework (Tan et al., 2019)

This framework was the first step to establishing an integrated STEM curriculum. The next step was to implement the lessons in the classroom. Dr Aik-Ling Tan and her colleagues identified four features that must be found in an integrated STEM classroom:

a. Problematizing: Teachers and students should engage in detailed discussions of the context in which complex, persistent and extended authentic problems were situated. The discussions would enable students to identify different problems and issues, how they interacted with the specific contexts, and appreciate the limitations of any existing solutions.
b. Group problem-solving: There ought to be opportunities for students to engage with group problem-solving. This could be in the form of collaborative or cooperative problem-solving. Students could participate in intra-or inter-groups to present, critique, defend, and improve their ideas collectively. Discussions should revolve around identifying parameters, balancing trade-offs, and how the needs of students could be met.
c. Design: Students should engage in the design process to create workable models or prototypes of their ideas. The design process would allow them to evaluate the feasibility and practicality of their proposed solutions. Depending on the availability of resources (such as time and materials) and the profile of students, the design process could include drawings, and building models.
d. Interdisciplinary solutions: When generating solutions, opportunities should be created for students to make connections between the proposed solutions, the different disciplinary knowledge, the epistemic practices, and the context of the problem. Teachers should provide relevant scaffolds to facilitate students' evaluation of their solutions in light of the context and the epistemic and conceptual links of the disciplines in STEM.

While the problem-centric integrated STEM lessons generated a lot of ideas, there were practical constraints in implementation. For instance, the solutions that were generated by students could be highly divergent. Teacher may not know how to assess learning outcomes against predetermined criteria. These feedback from teachers were considered and the framework has evolved to use solution-centric and user-centric lessons to anchor integrated STEM lessons (Teo et al., in-press).

3.4 Assessments

According to Gao *et al.* (2020), most of the assessments employed in secondary and tertiary interdisciplinary STEM educational programs between 2000 to 2019 failed to assess interdisciplinary knowledge and skills. Instead, these programs focused on assessing monodisciplinary knowledge, monodisciplinary affective domains (e.g., attitudes, awareness, beliefs and interest toward specific STEM discipline and their related careers), and transdisciplinary affective domains (e.g., interests toward STEM, self-efficacy and willingness to major in STEM disciplines).

Gao and her colleagues identified two challenges behind assessing interdisciplinary learning: (a) lack of consensus on the integrated STEM terminology (Sanders, 2009; Moore & Smith, 2014), and (b) inconsistency in the curriculum, instruction and assessment in these interdisciplinary programs. Collectively, it meant that integration across disciplines were often implicit, or little details were given on the strategies used to connect and integrate the various disciplines. If these programs could assess students' understanding of the connections across disciplines, it would lead to a more realistic evaluation of its effectiveness in producing better student outcomes.

Additionally, Gao *et. al* (2020) also noted the limitations of current approaches used to assess practices in STEM education. They reported that the majority of the assessments on engineering practices focused on the final product, rather than on the iterative nature of engineering design. Besides engineering design, other learning practices such as problem-solving, interdisciplinary reasoning and communication processes, and collaboration should be included in the assessment of STEM education. It was, therefore, important that university instructors were trained in identifying the right assessment tools for different STEM lessons.

3.5 Marketing Communication Plan

An integrated STEM program could be considered as successful if it led to a higher number of graduates joining the STEM workforce. A good marketing communication plan would create more awareness of these programs amongst employers. Some suggestions included:

a. Getting industry-related bodies to endorse the program (i.e. accreditation)
b. Having regular interactions between the university fraternity (leaders, instructors and students) and the industry
c. Pitching the benefits of the integrated STEM program to employers and investors
d. Tapping on new media in market communications to create greater public understandings about the knowledge and skill sets of integrated STEM graduates

Section 4: Gender Inclusivity

STEM-related occupations were expected to grow in the coming decades (Lund, *et al.*, 2019; Kramer *et. al*, 2014; Philomin, 2015), suggesting that more STEM graduates would be needed to fill these positions. If STEM initiatives are to be informed by diverse perspectives, Dr Sonya Martin contended that equitable access to STEM education and participation in STEM careers must be ensured. However, she noted that women remained underrepresented in STEM education and careers globally (UNESCO Institute for Statistics, 2021; Nathan Associates Inc., 2016; Van Tuijl & Van der Molen, 2016).

Dr Sonya Martin asserted that there were economic, social justice, environmental, and diversity impact due to the inequitable representation of women in STEM (Achiam & Holmegaard, 2020). First, STEM careers generally command higher salaries than other careers. If women were excluded from these careers, they would have less economic stability and opportunity. Second, when women had inadequate knowledge, it would be difficult for them to contribute to decision-making about important issues, for example, concerning their health. Women had historically been the ones who borne the brunt of many environmental concerns. If they were under-represented in STEM, it would decrease their potential to contribute new sustainable solutions to environmental threats. Finally, there were diversity concerns. When there were fewer opportunities for diverse perspectives to be included, the types of research, products, and solutions would be limited.

4.1 The STEM Gender Gap

Gender inequity in STEM participation remains a key concern for educators, researchers, governments, and policymakers (e.g., UNESCO, 2021; UNDP, 2021; UNESCO Office Bangkok and Regional Bureau for Education in Asia and the Pacific, 2020). Many studies from the last three decades revealed that gender differences in education and employment outcomes continued to persist. According to Dr Sonya Martin, this was despite the fact that:
(a) children of all genders attained similar scores in mathematics and science (Griselda &

Megalokonomou, 2020; OECD, 2020), (b) the same numbers of girls and boys completed secondary education (Gerstmann, 2020), and (c) more women graduated from university than men in many economies (Bilton, 2018; Francis, 2007). Men continued to represent an overwhelming majority of students studying STEM fields in higher education, especially in physical science, computer science, math and engineering (George-Jackson, 2011).

The labor gender gap was especially high in STEM fields and had always been male-dominated. Since STEM jobs were expected to experience strong growth (Lund, *et al.*, 2019), this gender gap would likely widen. For the few women who began their careers in STEM, they reported high rates of discrimination in male-dominated workplaces (Funk & Parker, 2018). They also experienced isolation due to a lack of access to women peers, role models, and mentors (Madgavkar *et al.*, 2019). Additionally, women were employed in lower-paying STEM occupations or earned lower wages than men even when they held the same STEM jobs (Funk & Parker, 2018). Likewise, the attrition rate for women was disproportionately higher than men, particularly for women who were also parents (Frank, 2019, Else, 2019).

Comparisons were made based upon the statistics in three APEC economies – Australia, the United States, and the Republic of Korea (Nagaraj, 2021; Australian Government, 2020; Catalyst, 2020; Finkel, 2020; WISET, 2019). In Australia, while women were employed in half of all non-STEM jobs, the employment of women in STEM only increased by 3 percent since 2009 (Australian Government, 2020). This was a small gain in over a decade. In STEM research, 7,500 women or 29 percent of them were employed in the academic workforce in 2017 (compared to 18,400 men) but accounted for only 12 percent of those in the highest academic seniority levels (Level E – Professor). In the private sector, women constituted 27 percent of the pool of STEM professionals. The underrepresentation of women in STEM jobs was further aggravated by the COVID-19 pandemic. It was reported that women in Australia's professional, scientific and technical services industry was down 6.3 percent for women (compared to 4.8 percent for men) from mid-March to mid-April 2020 (Finkel, 2020)

In the United States, more women obtained higher levels of education but they remained underrepresented and underemployed in most STEM education and careers, especially in engineering and computer sciences (Catalyst, 2020). The COVID-19 pandemic had worsened women's situation by displacing more women from school and the workforce at a higher rate than the pre-pandemic period. Since February 2020, nearly 1.8 million men left the US workforce, versus 2.3 million women who left the labor force during the same period. This placed women's labor force participation in the United States at 57 percent, the lowest since 1988. The disproportionate and greater impact of the pandemic on women could be due to the rising burden of childcare when schools switched to more home-based and online learning during the pandemic (Nagaraj, 2021). The social distancing requirements meant that women who held most of the service-related jobs became unemployed. It might take a decade for women to regain these jobs in the workforce.

Although national and international assessments repeatedly showed that there were no significant differences in mathematics and science achievements between Korean boys and girls, females were still underrepresented in STEM degree programs. In a report published by the Center for Women in Science, Engineering and Technology (WISET), female students accounted for roughly one-third of all students entering Science and Engineering programs in Korea, and fewer of them pursued engineering than natural sciences. Engineering majors were overwhelmingly male and constituted nearly 80 percent of all degree seekers. Whilst the government had instituted a variety of educational policy initiatives since 2009 to boost female enrollment in STEM, there were little changes to the number of female students entering Science and Engineering programs. This, in turn, led to a lack of gender parity in both new recruitment and employment. More Korean men were recruited as new hires, or were employed in STEM, than women. Even when women were engaged, they were often assigned to temporary positions, and the likelihood for them to be promoted, or to serve in positions of power for research management projects, was low. Furthermore, data indicated a sharp drop in labor force participation for married women in their 30s, as compared to men of the same age. This gap was linked to career disruption for women due to child-care needs. Interestingly, married men of the same age experienced an increase in employment opportunities for the same reasons. As the number of veteran female scientists decreased, less gender diverse perspectives and experiences would be brought to the development of STEM research. Consequently, the few women who stayed may likely feel excluded from informal networks and decreased their opportunities to participate in the production of STEM knowledge.

4.2 Closing the STEM Gender Gap

There were many movements to close the STEM gender gap, starting with a gender-neutral approach to STEM education in the 1950s, female-friendly STEM in the 1970s, and a rising popularity of gender-inclusive STEM today (see Figure 4-1).

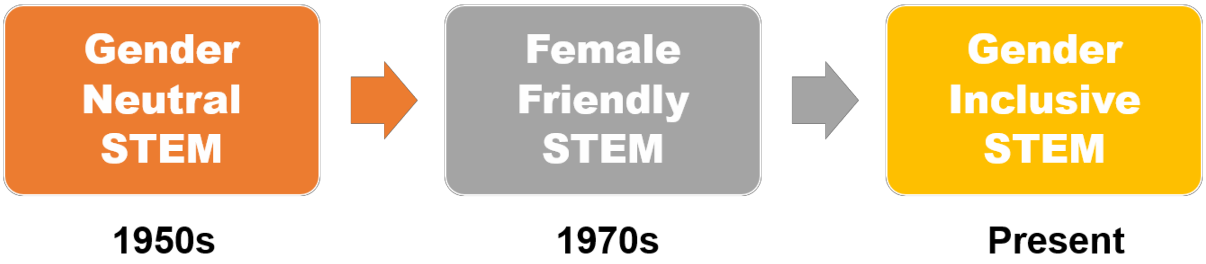


Figure 4-1 Evolution of gender approaches in STEM

(i) Gender-Neutral STEM

Gender-neutral STEM sought to realize gender equality by increasing the number of women or girls in STEM, without changing the curriculum, assessments, pedagogical approaches, or the culture of learning or doing research. The underlying assumption was that boys and girls were equal in their approaches to learning and interests in STEM. The obstacles associated with girls' lack of participation originated from "outside of STEM" (see Appendix 7, Slide 14). Thus, the answer to the gender gap was to 'add' women or girls to the existing structures.

Some of the affirmative action policies that were implemented to achieve gender equality included creating more pathways and tracks so that women or girls had greater access to STEM education, changing admission and enrollment guidelines in the universities, and attracting more women into STEM teacher education programs. Likewise, there were hiring policies that placed more women in STEM tenure-track faculty and research positions.

(ii) Female-Friendly STEM

As more women entered the workforce including research, there was a shift from a gender-neutral to female-friendly STEM education in the 1970s. This era recognized gender differences and focused on tackling these differences in the STEM learning environment. Attention was paid to the notion that there were feminine "ways of knowing and doing science", and that science teaching and learning should acknowledge this (see Appendix 7, Slide 16).

More STEM-friendly toys for girls were created. Other than making these toys pink or pastel, there were dolls featuring women in STEM professions and science kits for children that are specifically oriented to "girls' interests". For example, science kits on how to make lip balm and cosmetics, and the Gilbert Lab Technician Set for Girls (Science History Institute, n.d.) were sold.

In schools, female-friendly STEM practices emphasized on creating learning environments where the interests, experiences, and abilities of girls and women were represented in the curriculum. However, these ideas were 'assumed' interests, experiences, and abilities of girls and women, and did not acknowledge the different ways of being female (see Appendix 7, Slide 21).

The assumptions that girls and boys belonged to distinct, internally homogeneous groups based on their biological sex, created stereotypes about what it meant to be girls and boys that "fits no one in particular" (Brickhouse *et al*., 2000: 442). The inference that sex equals gender is now being challenged. Many researchers today view gender as something individuals do or perform, rather than something they possess. Thus, gender research in STEM is increasingly being studied as practices that are enacted, and not as fixed characteristics attributed to individuals based on sex (Achiam & Holmegaard, 2020). This has led to the emergence of inclusive STEM education with a gender focus.

(iii) Gender-Inclusive STEM

Described as a post-modern approach, inclusive STEM education creates possibilities for students to enact appropriately gendered identities that might challenge and broaden normative conceptions of masculinity and femininity, race, and social class (Danielsson, 2012). Gender-inclusive STEM recognizes that interests, capabilities, personalities, and aspirations vary widely within groups of biological sexes, and between the groups from all social categories (see Appendix 7, Slide 23). This approach tries to unpack how gender and other intersecting identities could inform STEM teaching and learning experiences.

According to Atwater (2011), the basic premise of an inclusive (multicultural) STEM classroom is:

a. All students can learn STEM.
b. Every student is worthwhile to have in the STEM classroom.
c. Diversity should be appreciated and valued because it enhances rather than detracts from the richness and effectiveness of STEM teaching and learning.
d. Pedagogical strategies that were designed to meet the needs of individual students should be adopted.
e. STEM educators, curriculum designers, and administrators should develop learning environments that respect the differences of students.

Despite the efforts made to reverse the low representation and attrition of women in STEM, numerous barriers in higher education havehad a negative impact on the interest, preparation, persistence, and STEM graduation rates among women and underrepresented students.

4.3 Overcoming Barriers to Women's Participation in STEM

Below were some obstacles identified to limit women's participation in STEM:

a. A continued lack of curriculum development and relevance to students' lives, regardless of gender
b. 'Chilly' climate in STEM campus and laboratories (e.g., no female restrooms in the buildings or on every floor)
c. Lack of appropriate academic preparation at their early age
d. Lack of awareness of STEM careers
e. Lack of hands-on STEM experiences for girls before they enter university
f. Lack of role models, mentors, and peer networks
g. Limited access to networks for internships or employment pathways
h. Limiting views that in turn affect women's perception of themselves
i. Parental and teacher expectations
j. Stereotypes about who are STEM and computer scientists
k. Stereotype threat on women's STEM abilities
l. The effect of microaggressions (e.g., the excessive use of male images in STEM textbooks and 'gendered' languages in classrooms, signaling that women do not 'belong' in STEM)

It had been widely argued that if diversity were to be a goal of STEM education, it was pertinent to approach the above barriers using different approaches. First, to attract more women and girls into STEM programs. This could be addressed through lesson design and delivery. Curriculum designers could use the Framework for Institutional Science Education (Achiam & Holmegaard, 2020) to shape their curriculum. To drive recruitment, it is essential to organize outreach programs to raise awareness of the various STEM career pathways that would be available upon graduation. The funding of more STEM research that engages disaggregated data to explore diversity would help educators formulate better strategies to attract more women into STEM.

Second, to continuously engage, support, and retain women once they are in a program. This involves selecting instructional practices that encourage inclusivity and ensures that innovative teacher education programs are in place to support educators to reskill themselves for new challenges in STEM teaching.

Third, systemic programs that provide longitudinal support for diverse people seeking STEM careers should be implemented. This would help promote women who have entered the STEM workforce to positions of power. The rest of this section elaborates on each of these strategies.

(i) Framework for Institutional Science Education

Achiam and Holmegaard developed a framework that considered gender, and promoted gender inclusion in science education activities. It examines how conditions and constraints at the individual, interactional, institutional, and societal/cultural levels could shape STEM activities in ways that include (or exclude) various types of students. Using a series of questions (see Appendix 7, Slide 27) as guideposts, STEM educators, curriculum designers, and administrators could become more aware of student differences. Consequently, it would support them in developing more inclusive curricula, instructional practices, and learning environments.

(ii) Instructional Practices that Encourage Inclusivity

Curriculum that advocates inclusive STEM tends to be student-centric and engaged students in problem-solving. Some examples of student-centric lessons are: (a) project-based learning, (b) STEAM education, (c) maker education, and (d) collaborative learning. Studies (see e.g., Thibaut, et al., 2018) have affirmed that these practices are effective in meeting the learning needs and interests of a wide variety of students, regardless of gender.

(iii) Innovative Teacher Education Programs

To support educators in their professional development and ensure that they stays updated on the latest in STEM research and instructional practices, programs that allow multiple pathways and flexibility in continual upskilling and reskilling could be set up. A good example would be the MiniMasters™ offered by the Nanyang Technological University, Singapore (Nanyang Technological University Singapore, n.d.). Teachers and other professionals may pursue a full-time job while studying and be able to choose from a variety of courses that are stackable towards a MiniMasters™ certificate. Credits earned in these courses could also be accredited to a full Master's degree by completing more courses.

(iv) Use Disagregated Data in STEM Research on Gender

Current research on gender difference is primarily based on a comparison of numbers (e.g., Lee & Lim, 2018). This could lead to data bias because this research fails to examine the roles played by other intersecting identities, such as race, class, and culture. There were studies that implied that data bias in engineering design and the development of artificial intelligence systems could harm future societies (D'Ignazio & Klein, 2020; Criado Perez, 2019). Dr Sonya Martin appealed for an increase in funding for STEM research that engaged disaggregated data to explore diversity issues.

(v) STEM Career Awareness Programs

STEM career awareness programs should be organized for parents, teachers, and students. When there are better understandings of the career routes and opportunities offered by an integrated STEM degree program, it could promote women's enrollment into STEM fields.

(vi) Systematic Programs

Three examples of longitudinal programs that had supported diverse students in STEM education and leadership were provided in Dr Sonya Martin's keynote presentation. These programs are discussed below.

<u>Girls Who Code</u>
'Girls Who Code' is a non-profit organization that aims to support and increase the number of women in computer science, close the gender employment gap in tech jobs, and change the image of a computer science program. With free coding programs ranging from one to two hours a week, to two weeks (Girls Who Code, n.d. [a]), their programs are designed specifically for girls, and took into consideration intersecting identities, such as race, class, and language. As these programs are multi-tiered, they support girls at different entry points. Through these programs, girls are able to develop coding skills, gain knowledge about possible careers, and build formal and informal social networks.

By 2021, 'Girls Who Code' had served 300,000 girls globally, with half of them coming from historically underrepresented minorities. Between 2017 and 2018, only 12,500 females graduated with a Computer Science degree in the United States. In the same period, 'Girls Who Code' had 80,000 members who were college-age alumni. Of those who were still in school, they chose Computer Science or related fields as their majors at a rate of 15 times more than the national average (Girls Who Code1, n.d. [b]).

<u>Posse Program</u>

The second example was the Posse program run by the Posse Foundation. The program recruits students from middle and high schools who are believed to have extraordinary academic and leadership potential but who might be overlooked by traditional college selection processes. Ten students are selected and placed into a multicultural team called a 'Posse'. The Posse Foundation then partners with colleges and universities to award these students full-tuition scholarships (The Posse Foundation, 2020). Selected students undergo eight months of pre-collegiate training. Once on campus, they would undergo a four-year program that support them in continuous professional development. This includes specialized immersive summer workshops and access to mentors. Posse students are also provided with a career program, and all of them have access to the Posse network.

Since 1989, Posse has partnered with 63 colleges and universities and awarded $1.6 billion in scholarships to more than 10,000 scholars. Posse scholars graduate at a rate of 90 percent, as opposed to the national average of 59 percent in the United States. Within five years of completing their undergraduate degree, 57 percent of them were first-generation college graduates. 48 percent of Posse scholars have either enrolled or already completed a graduate degree. Also, more than 80 percent of Posse scholars took on leadership roles in college. In 2012, the first STEM Posse was formed. The significance of the Posse programs could not be undermined. They benefit individual students and aid top research universities in expanding their diversity on campus. For instance, there are now more welcoming spaces in these partnered institutions that improved the support, retention, and recruitment of minorities in these universities. And because many of the Posse scholars were involved in leadership roles, they could hopefully develop and support sustainable change over time.

<u>Experimental and Project-based Engineering Courses by Massachusetts Institute of Technology (MIT)</u>

The last example would be the experimental project-based subjects that were introduced to first-year students at the MIT (USA). Students who chose to enroll in these courses were tasked to work in teams to design or create, synthesize knowledge from different disciplines, and apply this knowledge in solving real-world problems. Students were engaged in self-guided learning to complete the tasks assigned by the faculty, and assessments were based on project-based outcomes.

Interestingly, slightly more females (52 percent) chose to enroll themselves in these experimental, project-based engineering courses than in the regular engineering courses (45 percent). Females in these project-based courses were far more likely than females in non-project-based courses to interact with faculty members outside of class about their interests, and perceived them as encouraging and helpful. Correspondingly, faculty members were able to know these female students well enough to write them letters of recommendation. Females in these project-based courses were also more confident of their teaming skills. When working with technology, they had significantly higher self-confidence in their ability to perform technology-oriented tasks (see Appendix 7, Slide 37).

(vii) Other Approaches

Other approaches that were suggested by seminar participants to improve women's participation in STEM include:

a. Create wide faculty mentoring networks so that women at all stages of their STEM careers could receive and give mentoring
b. Design programs that engaged students in real-life problem-solving as this could lead to an increase in female enrollment
c. Host "Women in Science" career days for girls on campus

d. Incorporate discussions of gender issues in specific STEM professions during lessons
e. Integrate active learning into all STEM courses, especially at the early phase of STEM courses
f. Integrate activities such as Scientist Spotlights where students could see the diversity of scientists working in their fields (Foothill College, 2021)
g. Make balanced gender representation a hiring priority
h. Remove names and pronouns from candidate materials so as to reduce bias in hiring and graduate admissions
i. Sponsor science camps such as SPICE (SPICE Science, n.d.) for girls
j. Support student or programs that advocated gender equality (e.g., the Women in Graduate Sciences organization (University of Oregon Women in Graduate Sciences, n.d.))
k. Undertake interventions that reduced gender bias among university staff and students

4.4 Infusing Inclusivity in STEM Program

During the small group discussions, the participants were asked to propose ways to infuse gender-inclusivity into the course design, instructional practices, and the assessment of a STEM program. Three approaches were discussed and presented below.

(i) Equal Treatment of Genders

The first approach stressed equal treatment of both genders. Their recommendations emphasized on setting the same expectations for all students and having gender equality policies established at the university level. In this approach, STEM is viewed as a fair competitive ground for all genders. Thus, everyone could excel in STEM if they could perform the tasks required by the job.

Dr Paola Magni, a forensic scientist from the Murdoch University (AUS), cited an example from her collaborative overseas program co-planned with Universiti Kebangsaan Malaysia (also known as The National University of Malaysia) (MAS), where forensic science students from her university participated in a crime or disaster investigation in a mock-up exercise in Malaysia. During the recruitment phase, Dr Magni made sure that students of both genders were allowed to apply for the program. She ensured that the students worked in mixed teams. She emphasized to her students that they had to adapt to the environment and contribute equally to the work.

(ii) Normalizing Female STEM Professionals

The second approach was to normalize the idea of a female STEM professional so as to instill a sense of natural existence and belonging amongst women in STEM. This involved inviting female professionals and experts to speak to students on their experience as a woman in STEM, hiring more female academics, and having them act as role models for female students. If the female students have fears of failure, the university instructors could organize talks to share about their own obstacles at work, to bring across the message that failures were part of the learning experience in any STEM profession. University instructors should also be trained to avoid the use of gendered languages in lessons.

(iii) Raise Awareness and Cater to Gender Differences

The third approach was to raise awareness of gender differences, and to address these differences. Below were recommendations to raise the awareness about gender differences:

a. Afford opportunities to have dialogue about gender-related topic in the lesson activities
b. Ensure a good representation of both genders in teams formed In STEM lessons
c. Ensure equal distribution of roles and responsibilities during group work
d. Engage in universal design –that looked at how a solution could be accessed, understood, and used to the greatest extent possible by all people (regardless of age, size, ability, or disability) – so as to facilitate the infusion of inclusivity into solving STEM problems
e. To be consciously aware and sensitive to cultural differences when designing STEM problems and solutions

To cater to gender differences,

a. A mixture of individual and group assignments would help students build individual and relative confidence.
b. A variety of self-paced, bite-sized, and even online courses would encourage more women and other underrepresented minorities who had a heavy family commitment or could not pursue a full-time course, to get themselves enrolled into the program;
c. Assessment should be based on how students incorporate human differences (e.g., roles, needs, preferences) to create sustainable, equitable, universal designs; have a combination of individual and team assessment criteria in project-based assignments, or students could determine how they want to be assessed.
d. Instructional practices such as project-based learning and collaborative learning would improve learning outcomes for all students.
e. University should allow students to submit their past projects and portfolios for consideration when they applied for a STEM program.

Section 5: Curriculum Models

The foremost question that curriculum designers should ask before embarking on the design a new STEM program could be: "What STEM knowledge and experiences are of most worth?" From this information, STEM program designers could determine the types of STEM courses and topics that would draw out these knowledge and experiences, and the sequence of enactment.

5.1 Establish the STEM Knowledge and Experiences

To determine the STEM knowledge and experiences that should be built into a curriculum, the curriculum designer could evaluate curriculum worthiness from a student's perspective, the perspective of the curriculum designer, or from an economic perspective.

(i) Student's Perspective

In the literature, there were two methods that could support curriculum designers in determining the types of STEM knowledge or experience from a student's perspective. One of them would be through the lens of theoretical perspectives. These perspectives ranged from traditional, experiential, behavioral, and constructivist domains that uphold the structure of the discipline. Each perspective embodied a different set of ideas and key questions (See

Appendix 8, Slide 9). Any of these perspectives could act as the anchor to expand into other forms of knowledge and experiences that were critical to the students.

The second method was based on a model of relevance devised by Stuckey *et. al* (2013). Under this model, the chosen STEM knowledge or experiences were deemed relevant if it:

a. Led to positive consequences in student's life. Positive consequences could include fulfilling the actual needs that they are aware (e.g., personal interests and educational demands) or not aware of (e.g., anticipated future needs)
b. Aligned with students' interests and motivations (i.e. intrinsic needs), as well as expectations from the environment and society that they lived in (i.e. extrinsic needs)
c. Contributed to student's intellectual skill development (individual dimension), promote their competency in present and future participation in society (societal dimension), and increase their awareness of career choices (vocational dimension).

(ii) Perspective of the Curriculum Designer

While the above two methods assessed the worthiness from a student's perspective, it was important to consider the influences surrounding the curriculum designer. Influences such as - the society that the curriculum designer lived in, the nature of the work, the environment that the curriculum was enacted, their personal upbringing, school culture, the impact of technology on STEM fields, and the faith-based institutions that they were affiliated to - could affect the knowledge and experiences that would be included and how they are prioritized.

(iii) Economic Perspective

The priorities of each economy would also inform what were considered as important in the curriculum. For example, the competencies or skills that were deemed crucial in an agricultural-based economy might be different from that of an industrial-based, or knowledge-based economy.

Besides addressing worthiness from the perspective of the stakeholders listed above, designing an integrated STEM curriculum posed unique challenges because there were many questions about integrated STEM that remained unresolved:

a. Since STEM draws on existing disciplines, is there a unique disciplinary structure for integrated STEM?
b. Are there overlaps or contradictions in how various STEM disciplines explain and justify new knowledge claims?
c. Is it true that integrated STEM education is just about the application of knowledge and engaging activities? Can integrated STEM generate new knowledge?
d. What is the value proposition of an integrated STEM education?
e. What specifics do you want your economy to focus on in an integrated STEM education?

According to Dr Yew Jin Lee, there was no single or right curriculum model for an integrated STEM education. This meant that curriculum designers had the flexibility to craft out a program that was useful and applicable for students.

5.2 Ascertain the STEM Courses and Topics

After establishing the STEM knowledge and experiences that the new curriculum should embrace, a curriculum designer would need to determine the general structure of the curriculum, by identifying the types of courses and topics that would bring out these knowledge and experiences. Five aspects to uncover and organize these courses and topics were suggested: (a) macro-and micro-levels, (b) vertical and horizontal dimensions, (c) presentation of content, (d) top-down and bottom-up approaches, and (f) project-based. The infinite variety of curricula were derived from the variation and combination of these elements.

(i) Macro-and Micro Levels

The macro-level was the broadest level of organization of courses and topics for a program. Considerations at this level include examining how and when a course or topic should be introduced, whether a program was intended for undergraduate, or postgraduate levels, and which university or department/college should own the course. At the micro-level, the relationship between conceptual ideas (e.g., assessment and objectives) within a course are ascertained. It was possible to have several in-between levels because macro and micro level planning depend on the actual program structure. For instance, a macro level plan may become a micro level plan when a course was considered against an entire program offered by a college comprising multiple departments.

(ii) Vertical and Horizontal Dimensions

There were vertical and horizontal dimensions in a curriculum, but a curriculum designer could decide on the area of emphasis. The vertical dimension comprised links across time or grade levels to ensure students had the pre-requisite knowledge before introducing new content to them. For example, students should learn about genetics before evolution. Proper sequencing would enable students to deepen their skills and knowledge by building on what they had learnt. The horizontal dimension, on the other hand, made links across disciplines or courses. If a student was learning about enzymes, they should ideally be learning about graphs that are often used in representations of data about enzymes. In this case, enzymes and graphs were co-requisite units within a course.

(iii) Presentation of Content

There were four ways to present a curriculum content: (a) flat or discrete, (b) hierarchical, (c) linear, and (d) spiral. In a flat or discrete, each course or topic was designed to be self-contained. The MiniMasters™ of Science Education program offered by the National Institute of Education, Nanyang Technological University (SGP), is an example of a flat way of presenting content. Students could take the four courses in any sequence and accumulate sufficient credits to earn a MiniMasters™ certificate.

Content that were presented hierarchically would require students to first complete the content at the lowest level, before progressing to the next level. Many science curricula presented their content in this way. The Bachelor of Science (BSc) program in Integrative Systems and Design is an integrated STEM program that adopted the hierarchical presentation format (The Hong Kong University of Science and Technology, n.d.). Under this four-year program, students would need to acquire the fundamental design and technical courses before they could progress to design integrative systems in their second-, third- and fourth-year projects

On the contrary, mathematics curricula tend to present the content in a linear manner. The Bachelor of Mathematical and Computer Sciences is one such example (The University of Adelaide, n.d.[a]). Students would need complete STATS 1005 Statistical Analysis and Modelling I in their first year, before they could take on STATS 2107 Statistical Analysis and Modelling II in their second year. Figure 5-1 is a graphical illustration of how content could be presented as flat or discrete, hierarchical, or linear.

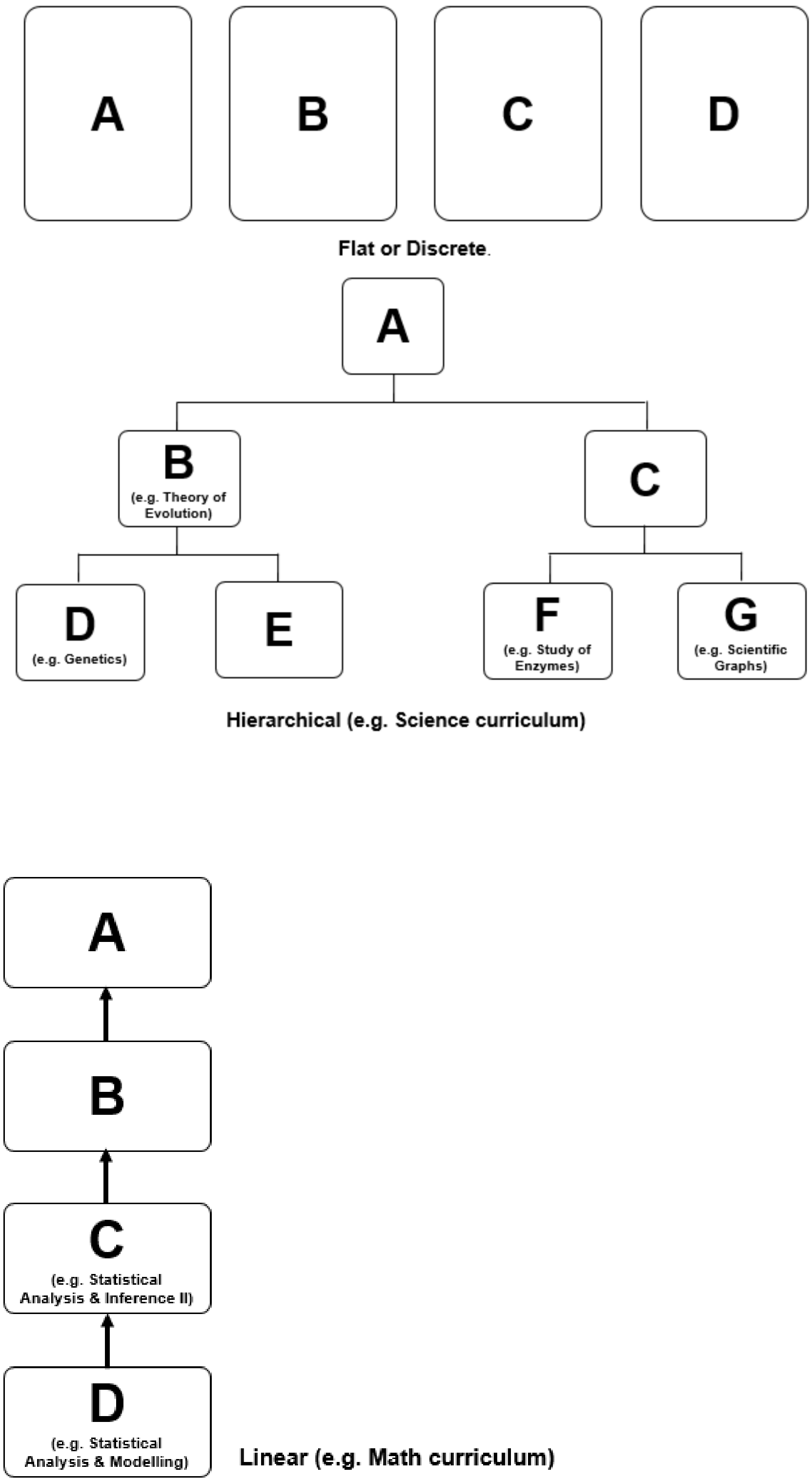


Figure 5-1 A graphical illustration of the flat or discrete, hierarchical, and the linear way of presenting curriculum content

There were many examples in STEM that presented its content in a spiral format (see Figure 5-2). With this format, themes, topics, and concepts were covered across a year, or multiple years. As the student moved through the years, they would gain new insights of the theme, topic or concept, thereby deepening and expanding their knowledge and experiences. The courses in the Bachelor of Food Science and Technology (Monash University Malaysia, 2021), and the Bachelor of Viticulture and Oenology (The University of Adelaide, n.d. [b]) took on a somewhat spiral format in their content presentation. In the Bachelor of Food Science and Technology, there was a deepening and expansion of the topic on food science over the three-year degree program. Students would learn about food, sensory practices and nutrition in their first year, food chemistry in second year, and advancing to food and industrial microbiology, and functional foods in their third year. For the Bachelor of Viticulture and Oenology, students would acquire basic sciences (e.g., chemistry, biology, physics) and foundations of wine science in year one, followed by an emphasis on the scientific and technological aspects of winemaking and viticulture in years two and three. They would then be given the opportunity to complete an internship in viticulture and/or oenology to further deepen their knowledge and experiences.

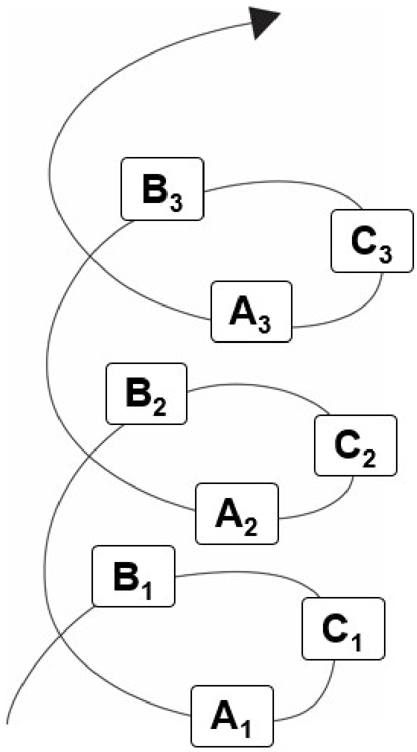


Figure 5-2 A graphical illustration of a spiral way of presenting curriculum content

(iv) Top-Down and Bottom-Up Approaches

The top-down approach followed the structure of a discipline and organized knowledge from a disciplinary perspective. A few big ideas would first be identified, and they became the 'hooks' to hang all the subsuming ideas. A curriculum that was organized using a top-down approach simulate how a real STEM professional in the discipline would think and conduct inquiry. Bottom-up approach, on the other hand, sequence knowledge from a student's perspective. Examples of question addressed were: How should knowledge be sequenced so that it would improve student's learning? What were some prior skills or experiences that a student must have before they could participate in the activities at higher levels?

(v) Project-Based

In a project-based curriculum, the project, which usually happened at appropriate points, sought to help students consolidate and apply the knowledge that they learnt throughout the curriculum. The IQWST® (Investigating and Questioning our World through Science and

Technology) program in the USA is an example of a middle-school STEM curriculum that was organized using a project-based approach (Activate Learning, 2017). Students in the IQWST® program were expected to complete 12 inquiry projects over three years. Another example would be the "Haus der kleinen Forscher" or the Little Scientists' House program in Germany, an early childhood education initiative that focused on STEM fields (Stiftung Haus der kleinen Forscher, 2021).

5.3 Arrangement of STEM Courses and Topics

The last phase of curriculum design involved decisions on the arrangement of courses and topics within a program. At this point, the curriculum designer had to be mindful of: (a) the coverage – the types and number of courses and/or topics that should be incorporated, (b) quantity – the number of courses and/or topics to be included within a grade or grade division, (c) sequence – how these courses and/or topics should be ordered, and (d) focus – the emphasis (e.g., established by the number of learning outcomes or curriculum credits that were assigned to them per unit of duration) that should be placed on each course or topic.

To give an example, Dr Yew Jin Lee conducted a study that examined the number of learning outcomes assigned to the topics in K-12 integrated science textbooks used in two different economies. He found that one economy undertook a specialist approach because all the topics at one of the grade levels focused on a single science domain. All the topics that were taught at Grade 7 were associated with life sciences, while Grade 8 focused on physical sciences. In contrast, another economy took a generalist approach and gave somewhat equal emphasis on topics that were connected to three key science domains (i.e., chemistry/physics, earth science, and biology) across the years.

Dr Yew Jin Lee also described two visual patterns of topics that he thought were desirable in a good curriculum. First, there should be some key or 'buttress' topics that would be repeated over multiple years. These topics formed the pillars of the curriculum. The repetitions allowed students to deepen their knowledge of the topics. An extension of the previous pattern was the upper triangular pattern that had more challenging topics covered in the upper grade levels. This was believed to be present in better-designed curriculum too. Figure 5-3 shows an example of a curriculum that included buttress topics and displayed an upper triangular pattern.

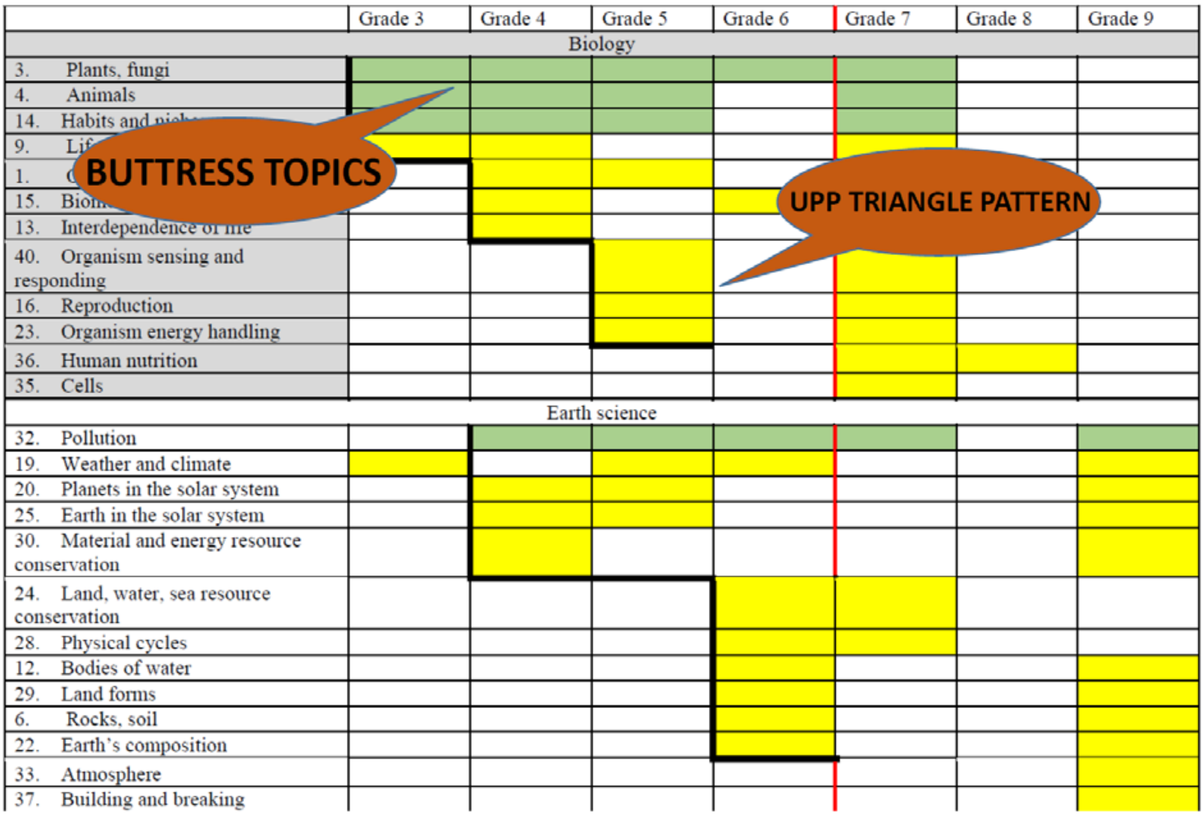


Figure 5-3 An example of a curriculum that included buttress topics and displayed an upper triangular pattern (Wan & Lee, in-press)

Beyond curriculum design, other elements that needed to be considered when planning a new undergraduate STEM program included budget and financing, establishing the owners of the courses and topics, entry requirements, assessment, and whether the degree would lead to more job or educational opportunities for students. These factors would impact the success of the new program. The Creative Matrix (Belozerova & Dooley, 2020) could be used as a tool to generate innovative solutions to these problems.

5.4 The Creative Matrix

The Creative Matrix (Belozerova & Dooley, 2020) was adapted for our integrated STEM curriculum planning purpose. It could be approached using the following steps:

<u>Identify the problems and opportunities</u>

a. Step 1: Identify a set of problems and opportunities that might arise from the planning of a new integrated STEM program. Pen them down as phrases.
b. Step 2: Add a starter "How might we" to the beginning of each phrase (i.e. problem) to convert them into an intent. This intention would set the basis for ideation.
c. Step 3: Place these intentions as the X-axis of the matrix.

<u>Identify the enablers</u>

d. Step 4: Think of categories that might enable solutions to the intentions identified in Step 3. Place these enablers as the Y-axis of the matrix.
e. Step 5: Assign a weight to these enablers (if needed).

<u>Brainstorm solutions</u>

f. Step 6: Brainstorm ideas to fill up the empty fields where the columns (i.e. problems and opportunities) and rows (i.e. enablers) intersect.

Table 5-1 depicts a list of possible intentions (on X-axis) and their associated enablers (on Y-axis) that could be considered in a Creative Matrix for a new integrated STEM program.

		HOW MIGHT WE (HMW) [Intent to do something together] E.g., Convince stakeholders that a new STEM program is needed? Ensure coherence of learning in an interdisciplinary program?							
		Weight	convince stakeholders that a new STEM program is needed?	**Weight**	ensure coherence of learning in an interdisciplinary program?	**Weight**	Collaborate with different faculties that are unfamiliar with or resistant to offering joining programs?	**Weight**	Create excitement among students to take this program?
People & Institutions	Teachers								
	Students								
	School boards/ ministry								
	Industry								
	Donors								
	Informal education providers								
	Planning team								
Contexts & policies	Contexts and culture:								
	Micro								
	Macro								
	Policies:								
	Micro								
	Macro								
Curriculum	Curriculum:								
	Purposes								
	Subject matter								
	Activities								
	Timelines								
	Accountability								
	Budget/funding								
	Resources								
	Technologies								

Table 5- 1 An example of a Creative Matrix for planning a new integrated STEM program

The following were some ideas proposed by participants using the Creative Matrix.

(i) How might universities convince the respective stakeholders that a new STEM program is needed?

Faculty/Teachers

a. Highlight the advantage of collaborative work with other researchers during cross-teaching
b. Talk about the possibilities that would be generated (e.g., in terms of research and promotion of teachers).

Students

a. Create an integrated STEM identity (i.e. What is a STEM-ist?)
b. Emphasize the positive experiences of cross-disciplinary learning and how it would better prepare students for the workforce
c. Ensure that the program would make students employable after graduation
d. Provide a flexible but robust program structure that could be configured to match individual interests and still aligned to the STEM program objectives
e. Use social media and talks to share about the experience of past alumnus in the program

School Boards / Ministry

a. Selling the "delta" (i.e., difference) that would make a STEM educator different from a Science or Math educator (e.g., epistemic fluency across disciplines in Reynante *et. al*, 2020).

Industry

a. Market the expertise of STEM graduates to the industry
b. Obtain accreditation or recognition from professional bodies before the new program is launched
c. Secure internships at STEM-related industries for students

(ii) How might universities collaborate with the respective stakeholders to offer such a program?

Students

a. Invite students to organize events and marketing campaigns to promote the new STEM program
b. Allow students to earn credits from self-designed courses or projects

School Boards / Ministry

a. Work closely with administrators to create pathways for students, so that they may be admitted into majors or programs that they are interested in and not based on high school grades alone

Industry

a. Collaborate in the design of capstone projects for graduating STEM students
b. Organize career information week
c. Collaborate with industry in program activities
d. Involve the industry in curriculum design
e. Invite STEM professionals as guest speakers
f. Encourage the industry to hire STEM students in internship programs

g. Involve female STEM professionals in science conferences for networking and job recruitment.

Policy-makers

a. Appoint industry professionals as professors/teaching staff/researchers in universities
b. Devise different promotion tracks for university instructors who are involved in integrated STEM programs
c. Create policies that encouraged students to enroll in STEM programs. For example, tax reliefs, scholarships, and lower tuition fees

(iii) How might universities ensure coherence of learning in an interdisciplinary program?

a. Ensure that the program comprise of disciplines that are integrated within each course rather than a collection of courses from different disciplines.
b. Adopt a "backward design" approach to curriculum design:
    - The goals and learning outcomes for an integrated STEM degree program must first be established, with attention given to equity in design
    - The profile of the graduates that the program aims to develop (e.g., are they going to be STEM consumers, STEM professionals, or STEM innovators?) will influence the types of STEM knowledge and skills that should be incorporated
c. Ensure that the capstone projects promote systems thinking and design thinking as a way to 'gel' the different disciplines in the program

Section 6: Recommendations

The seminar participants worked in groups to brainstorm a prototype of a STEM course that could be included in an integrated and gender-inclusive STEM degree program. Three course prototypes were proposed.

6.1 Course Prototype 1 - Biomimicry

a. **Course Synopsis:** In this first-year undergraduate course, students would learn from and mimic the strategies found in nature to solve human design challenges. Topics covered include biological diversity, animal and plant structure and their function, how the patterns of life could inform design, big data analysis, and creative IoT (Internet of Things) technology. A combination of case studies, parametric design, and collaborative learning could help students explore the connections between architecture, technology, science, and mathematics. As a project-based course, they would work in teams to design a prototype of an architectural building in nature.

b. **Course Outline:** A spiral structure is embedded in the proposed course design. Key topics, such as Biological Diversity would be discussed repeatedly over the course to inform students of their understanding of the different design principles. Table 6-1 provides an overview of the topics that were suggested for this course on Biomimicry.

Lesson No.	Suggested Topics	Comments / Remarks
1	Biological Diversity	There will be examples of how biological diversity is considered in architectural design
2	Animal and Plant Structure and Function	
3	Understanding Natural Behavior for Architectural Applications	How can architecture co-exist in harmony with nature?
4	Design Innovation & Prototyping and Educational Technologies	Students will learn about 3D modelling and parametric design
5	Biomimicry	
6	Energy Efficiency and Saving in Nature	
7	Patterns of Life and How these Patterns Can Inform Design	
8	Artificial Intelligence	
9	Big Data Analysis and Creative IoT Technology	
10	Green Environment Design	
11	Climate Change	
12	Water (Building, structures, resources)	
13	Final Project Presentation	

Table 6-1 Suggested topics for the course on Biomimicry

c. **Assessments:** As a project-based course, a combination of individual and team assessments would be used throughout the course. The team would be assessed on the prototype, report and team presentation. These constituted the components of the final project. In addition, a series of quizzes, research-based assignments, and peer reviews would be administered throughout the course to assess learning at the individual level.

6.2 Course Prototype 2 – Sustainable Energy Solutions

a. **Course Synopsis:** Positioned as an introductory or foundation course for Engineering, Computer Science, and Science-related programs, this undergraduate course would cover topics such as sustainable energy sources, issues, and solutions. The course would provide opportunities for students to explore various alternative and renewable energy sources such as solar, wind, and bioenergy. As part of the course, students would research about issues related to one of these renewable energy sources and present innovative solutions for sustainable development. Using a project-based approach, students would collaborate and work on a problem. At the end of the course, students would have acquired presentation skills, collaboration skills, and develop the mindsets necessary to take ownership in making the world a better place. This course would prepare students for a career in system development and energy-related industries.

b. **Course Outline:** A list of suggested topics for this course is found in Table 6-2.

Lesson No.	Suggested Topics	Comments / Remarks
1	Energy issues and concerns? Renewable Energy Sources	Include international standards for sustainable solutions.
2	System analysis and design: visualizing problems in sustainable energy.	
3	Data analytics for sustainable development: Tools, Technologies, Data Analytics? Big Data?	This can be taught by mathematicians, statisticians, and computer scientists
4	Exploring Solar Energy	To bring in guest speakers from the industries, as well as engineering and science faculty members
5	Exploring Wind Energy	
6	Exploring Biomass / Bioenergy	
7	Exploring Geothermal Energy	
8	Exploring Hydroelectric Energy	
9	Exploring Hydrogen as Sources of Energy	
10	Fossilized and non-fossilized sources of energy	
11	What is sustainability? Balancing tensions and integrating values	Understand nature from the perspectives of science, culture, and community development
12	Inter-cultural tensions and cultural impact	Include some gender inclusivity issues e.g., issues pertaining at workplaces in energy industries
13	Environmental impact	Can include careers in this field?
14	Project presentation: International standards for sustainable solutions	

Table 6-2 Suggested topics for the course on Sustainable Energy Resources

c. **Assessments:** Students would be assessed through their project-based assignment and presentation, the videos that were produced to share on their innovative sustainable solutions, and ‘arm-chair’ research. An evidence-based assessment rubric would be created and used for this course.

6.3 Course Prototype 3 – Developing and Creating a Solution

a. **Course Synopsis:** This would be a core course that would be taken by most first-year undergraduate students in their second semester. At the end of the course, students would be confident and effective communicator. They would learn to work in teams, manage their time better, and understand that failures were part of the learning process. Students would also develop innovative thinking, systems thinking, be able to improvise, and lastly, have a growth mindset. As part of the course, students would design a project that is based on their discipline.

b. **Course Outline:** The topics would be arranged progressively. In lessons one to three, students would be exposed to a plethora of basic skills (also known as just-in-time skills) that might not be related to each other. By lesson four, they would form teams of three or four members, and attempt to apply the skills learnt to solve a problem. At the end of the course, the teams would showcase their work at a mini technology fair. An overview of these topics can be found in Table 6-3.

Lesson No.	Suggested Topics	Comments / Remarks
1	Basic skill development E.g., soldering	E.g., soldering, sewing, math models
2	Basic skill development (or just in time learning)	Coding, design, computer architecture, machine learning
3	Skill development and problem identification	Basic skill development
4	Identification of problems to work on (groups)	Assignment of individual roles in each group
5	Working on solutions - real world application of skills	Documentation of progress, use journal to record progress, and recording of practice videos
6	Solution - scale up from prototype Can also incorporate industry internship time for improving model development	• Industry involvement is optional/ accidental • Documentation of progress, use journal to record progress, and recording of practice videos
7	Discuss solution, includes consultation with expert (apply divergent/convergent approaches)	Documentation of progress, use journal to record progress, and recording of practice videos
8	Discuss solution, includes consultation with expert (apply divergent/convergent approaches)	Documentation of progress, use journal to record progress, and recording of practice videos
9	Develop models for simulation	Identify solutions that work
10	Identify discrete solutions	Prepare pitch - communication (four weeks of practice videos)
11	Elevator pitch Assessment - e.g., elevator pitch portion	In small groups (three to four members in a group), they will be based on: a. One elevator pitch b. One presentation Q & A c. Learning Video/audio

Lesson No.	Suggested Topics	Comments / Remarks
		d. Peer feedback/review
12	Real elevator Communication Assessment - e.g., Q & A portion	In front of tutors/ professors Equity – challenge
13	Main showcase - assessment	E.g., Mini Tech Fair

Table 6-3 Suggested topics for the course on Developing and Creating a Solution

c. **Assessments:** Students would be assessed largely at the team level. Each team member would be assigned to one of the following tasks which would form the basis for assessments: (a) elevator pitch, (b) question and answer session after the presentation, (c) weekly learning videos, and (d) the final report. Students could decide on the weights that they would like to allocate to each of these components. This would be done at the beginning of the course and before the last few lessons. At the individual level, the student would go through a process of benchmarking their performance against a set of criteria that were agreed upon between the tutor and the student at the beginning of the course. They would also receive feedback from their tutors, teammates, and even their clients on their performance. These would be considered in the assessment of the student at the individual level.

Based on the prototypes that were presented, it was interesting to note that none of them picked examination as a form of assessment. Gender-inclusivity was infused through the choice of pedagogies and assessment tools employed in these courses (Refer to Section 4.2 Part (iii) Gender-Inclusive STEM, and Section 4.3 Part (ii) Instructional Practices that Encourage Inclusivity). Table 6-4 summarized the similarities and differences of the three STEM courses.

	Biomimicry	Sustainable Energy Solutions	Developing and Creating a Solution
Types of Disciplines Included	• Mathematics, Science and Technology • Non-STEM (architecture)	• Science	• Basic skills learnt can be STEM and non-STEM • Standalone skills that may not be related to each other
Target Students	• First-year Science and Architecture students	• First-year Engineering, Computer Science, and Science students	• First-year, second semester • Available to students of all disciplines
Pedagogies	• Case studies • Collaborative learning • Parametric design • Project-based	• Project-based	• Project-based
About the Project	Design an architectural problem that will be located in nature.	Research issues in one of the renewable energy sources and present innovative solutions for sustainable development.	Identify a problem that could be resolved using the skills learnt. Students will then showcase their

	Biomimicry	Sustainable Energy Solutions	Developing and Creating a Solution
			solutions in a Mini Tech Fair
Individual Assessment Tools	• Quizzes • Peer Review • Research-based assignments	-	• Individual benchmarking • Review by peers, tutors and clients
Team Assessment Tools	• Prototype • Final report • Presentation	• 'Arm-chair' research • Videos that were produced to share on their innovative sustainable solutions • Final report • Presentation	• Weekly learning videos • Elevator pitch • Question and answer session after the presentation • Final report. Teams can decide on the weights to be assigned to each assessment component.

Table 6-4 A comparison of the three STEM course prototypes

Section 7: Conclusion

This project (HRD 06 2019A) built upon the work of other APEC projects (e.g., PPWE 04 2017S and PPWE 01 2016S) with a focus on STEM and gender inclusivity. In bringing together a group of STEM university instructors from APEC economies to actively participate in the co-construction of ideas for an integrated STEM degree program that embeds gender inclusivity in this human capacity project, it had acted upon the recommendation in the *APEC Women in STEM: A Framework for Dialogue, Learning and Action* to "encourage routine and active sharing of STEM-related experiences, insights, and methods among educators, schools, and universities across the region" (Nathan Associates Inc., 2016: 52).

To summarize, this report presented possible reasons behind the lack of integrated STEM programs in higher education and suggested ways to resolve them. Three integration models that could be applied in the design of inter-and transdisciplinary STEM curriculum at the university level were shared by the keynote speaker. Pedagogies that were appropriate for the delivery of integrated STEM courses were also discussed.

The enormity and complexity of gender in STEM education were reiterated. Constructive approaches to mitigate some barriers that women faced in STEM, and approaches to promote gender-inclusivity through careful curriculum design, selective instructional practices, and assessment in integrated STEM program were suggested. Using a curriculum matrix to frame the discussions, the participants considered the roles that universities can play and generated possibilities for actualizing plans for integrated STEM degree programs at their institutions. The capstone discussion about courses in integrated STEM programs resulted in three prototypes that embodied elements of STEM integration and gender inclusivity.

Through the participatory process of engaging in professional dialogues and co-constructing a model for an integrated STEM degree program, participants from the APEC economies had contributed to the pool of knowledge, competencies, and resources supporting the establishment and sustainability of STEM integration. Individual universities may contextualize the information if they choose to adopt or adapt the model. Through our collective efforts, we are hopeful that the APEC economies could move forward as a community in affording higher quality STEM degree programs that would result in improved quality of human capital to address the demands of the 4IR in STEM and beyond.

Appendix 1 – APEC Event Speakers and Participant List

Project Number: HRD 06 2019A **Event Date:** 23 to 25 March 2021
Project Title: Actualization of Integrated STEM Degree Programs: A Model to Inform, Catalyze and Shaper Inter- and Trans-disciplinary University Education

#	First Name	Last Name	Email Address	M/F	Speaker/Expert or Participant	Economy	Organization
1	Amanda	Able	amanda.able@adelaide.edu.au	F	Participant	AUS	The University of Adelaide
2	Brian	Ng	brian.ng@adelaide.edu.au	M	Participant	AUS	The University of Adelaide
3	Chris	Browne	Chris.Browne@anu.edu.au	M	Participant	AUS	The Australian National University
4	Gillian	Kidman	Gillian.kidman@monash.edu	F	Participant	AUS	Monash University
5	Paola	Magni	p.magni@murdoch.edu.au	F	Participant	AUS	Murdoch University
6	Rajendran	Parthiban	rajendran.parthiban@monash.edu	M	Participant	AUS	Monash University Malaysia
7	Malai Zeiti Sheikh Abdul	Hamid	zeiti.hamid@utb.edu.bn	F	Participant	BD	Universiti Teknologi Brunei
8	Nena	Valdez	nena.valdez@utb.edu.bn	F	Participant	BD	Universiti Teknologi Brunei
9	Christina	Schönleber	christina.schoenleber@apru.org	F	Participant (NMP)	HKC	APRU International Secretariat
10	Kam Tim	Woo	eetim@ust.hk	M	Participant (NMP)	HKC	The Hong Kong University of Science and Technology, Hong Kong, China
11	Ria Asih Aryani	Soemitro	ria@ce.its.ac.id; soemitroraa@gmail.com	F	Participant	INA	Institut Teknologi Sepuluh Nopember
12	Hye Jeong	Kim	hyejeongkim@cau.ac.kr	F	Participant	ROK	Chung-Ang University
13	Youngmin	Park	ympillow@sookmyung.ac.kr	M	Participant	ROK	Sookmyung Women's University
14	Sonya N.	Martin	sm655@snu.ac.kr; sonya_martin@fastmail.com	F	Speaker	ROK	Seoul National University, Republic of Korea
15	Lilia	Halim	lilia@ukm.edu.my	F	Speaker	MAS	The National University of Malaysia

#	First Name	Last Name	Email Address	M/F	Speaker/Expert or Participant	Economy	Organization
16	Madya Rosseni	Din	rosseni@ukm.edu.my	F	Expert (NMP)	MAS	The National University of Malaysia
17	Ruhizan Mohd	Yasin	Ruhizan@ukm.edu.my	F	Expert (NMP)	MAS	The National University of Malaysia
18	Salbiah Mohamad	Hashim	samohas1502@gmail.com	F	Expert (NMP)	MAS	The National University of Malaysia
19	Siti Nur Diyana	Mahmud	diyana@ukm.edu.my	F	Expert (NMP)	MAS	The National University of Malaysia
20	Jessica Alcantara	Rivera	divisionarquitectura@loscabos.tecnm.mx; jessialcantara05@gmail.com	F	Participant	MEX	TecNM Campus Los Cabos
21	Maria Aileen "Mylene"	Abiva	myleneabiva@yahoo.com; international.affairs@pcw.gov.ph	F	Participant	PH	Women Business Council of the Philippines
22	Sergey	Alekseev	Alekseev.sa@dvfu.ru	M	Participant	RUS	Far Eastern Federal University
23	Aik Ling	Tan	aikling.tan@nie.edu.sg	F	Participant	SGP	National Institute of Education, Nanyang Technological University, Singapore
24	Anjam	Khursheed	eleka@nus.edu.sg	M	Participant	SGP	National University of Singapore
25	Ban Heng	Choy	banheng.choy@nie.edu.sg	M	Expert (NMP)	SGP	National Institute of Education, Nanyang Technological University, Singapore
26	Danial	Seman	danial.seman@nie.edu.sg	M	Expert (NMP)	SGP	National Institute of Education, Nanyang Technological University, Singapore

#	First Name	Last Name	Email Address	M/F	Speaker/Expert or Participant	Economy	Organization
27	Emily	Lu	emilydlu@gmail.com	F	Participant	SGP	National Institute of Education, Nanyang Technological University, Singapore
28	Kim Chwee Daniel	Tan	daniel.tan@nie.edu.sg	M	Expert (NMP)	SGP	National Institute of Education, Nanyang Technological University, Singapore
29	Pi Lee Beverly	Goh	beverly.goh@nie.edu.sg	F	Expert (NMP)	SGP	National Institute of Education, Nanyang Technological University, Singapore
30	Yann Shiou	Ong	yannshiou.ong@nie.edu.sg	F	Expert (NMP)	SGP	National Institute of Education, Nanyang Technological University, Singapore
31	Yew Jin	Lee	yewjin.lee@nie.edu.sg	M	Speaker	SGP	National Institute of Education, Nanyang Technological University, Singapore
32	Eleanor	Vandegrift	ellyvan@uoregon.edu	F	Participant (NMP)	USA	University of Oregon, USA
33	Yan	Wang	wang_yan@moe.edu.cn; ywang08@qq.com	F			APEC HDRWG
34	Dasom	Kim	dasomkim@alcob.org	F			APEC HRDWG Lead Shepherd's Team

Appendix 2 – Pre-Seminar Questionnaire

A. About Respondent

A.1 Name : ☐

A.2 Designation : ☐

A.3 Name of Affiliated Institution : ☐

B. Existing STEM Curriculum

B.1 Does your institution or other institution(s) in your economy offer a STEM program at the undergraduate and/or graduate levels?

☐ Yes ☐ No (Please go to Section C)

B.2 Please elaborate on the STEM program(s) offered.

STEM Program

i. Name of Program and Institution : ☐

ii. Level *(you may choose more than one)* : ☐ Degree ☐ Masters ☐ PhD

iii. STEM Discipline(s) Covered *(you may choose more than one)* : ☐ **S**cience ☐ **T**echnology ☐ **E**ngineering ☐ **M**athematics ☐ Integrated **STEM** (S / T / E / M)

Please circle the disciplines that were integrated)

iv. Duration of program : ☐

v. Hours / Credit : ☐

vi. Program synopsis and course structure : *You may also provide website link or attach document relating to this information.*

vi. Website : ☐

vii. What were the critical success factors in designing the STEM integrated course?

☐

viii. Does the program addresses gender inclusivity and how?

C. Plans for a New Integrated STEM Degree Program

C.1 Are you aware of any plans by your institution or other institution(s) in your economy to start an integrated STEM degree program in the next 5 years?

☐ Yes ☐ No (Please go to Section D)

C.2 Share with us what you know about the program (e.g.,, goals, target audience, program structure, courses, recruitment methods, etc).

D. Design an Integrated STEM Degree Program

D.1 Do you think there will be a demand for an integrated STEM degree program? Why or why not?

D.2 If you are tasked to design an integrated STEM degree program, how do you envision it to be?

Proposed STEM Degree Program

i. STEM Discipline(s) to be integrated : ☐ **S**cience ☐ **T**echnology ☐ **E**ngineering ☐ **M**athematics

ii. Duration :

iii. Program synopsis :

iv. Topics that **MUST** be included :

v. Target Audience :

vi. Recruitment Method(s) :

D.3 In your view, what are the perceived obstacles towards the successful launch of the new program in Question D.2?

D.4 How best can these obstacles (mentioned in Question D.3) be overcome?

---- End of Questionnaire ----

Appendix 3 – Biographies of Keynote Speakers

Dr Lilia Halim, The National University of Malaysia (MAS)

Lilia Halim is a professor in Science Education at the Faculty of Education, The National University of Malaysia (MAS). Her research interest and work revolve around promoting scientific literacy through three main research thrusts; (a) Investigating and developing science teachers pedagogical content knowledge (PCK), (b) propagating pedagogical model for promoting innovative thinking in science and now known as STEM education and (c) exploring the role of nonformal science learning in the Malaysian context.

She was also involved in the roadmap planning for science and mathematics (2015-2020) for the Regional Science and Mathematics Centre (RECSAM) in Penang. In addition, she and the team from UKM were involved in the evaluation of the Malaysian education system that provided inputs to the Malaysian Education Blueprint 2013-2025. Lilia has also contributed to the resource pack on pedagogies for Girls in STEM as part of Malaysia/UNESCO – IBE Project, Strengthening STEM Curricula for Girls in Africa and Asia and the Pacific.

In terms of publications, Lilia has written research articles in science and mathematics journals and book chapters in publishers such as Kluwer, Springer, Routledge, and Sense Publishers.

Dr Sonya N. Martin, Seoul National University (ROK)

Sonya N. Martin is a tenured Full Professor in Science Education at the Seoul National University in Seoul, ROK. Prior to moving, Martin was a tenured faculty member at Drexel University in Philadelphia, PA in the United States where she was the Principal Investigator (PI) of a National Science Foundation (NSF)-funded (HRD 1036637) study examining the intersections of gender, ethnicity, and language learning in the context of middle school science.

Her focus in G-SPELL (Gender and Science Proficiency for English Language Learners) was on identifying science teacher practices that promoted language learning in the context of science inquiry with English Language Learners (ESL). She became particularly interested in exploring ways to improve collaborative teaching between science content and ESL teachers to promote beneficial science teaching practices for all students. In addition, she became interested in the science education experiences of the students in the study who had recently immigrated to Philadelphia from Asian countries.

To learn more about science education in Asia, Sonya accepted an international faculty position at the Seoul National University and moved to Korea in 2011, where she is learning Korean and actively engaging in collaborative research with colleagues in Asia. Currently, she is PI of a project in Korea examining the impact of digital literacy on students' science learning in online environments and for a project exploring science educators' responses to COVID-19in Korea and in international contexts.

Sonya serves Editor-in-Chief of the journal, Asia-Pacific Science Education, and she is an editorial board member for several journals, including Research in Science Education and Cultural Studies of Science Education. She also serves as the International Coordinator and board member for the international organization National Association for Research in Science Teaching (NARST)..

Dr Yew Jin Lee, National Institute of Education, Nanyang Technological University (SGP)

Dr Yew Jin Lee is an Associate Professor in the Natural Sciences and Science Education Academic Group at the National Institute of Education, Nanyang Technological University, SGP. His work entails teaching in primary science, secondary Biology education as well as in various masters/PhD/EdD level courses. As part of his doctoral work at the University of Victoria (BC), he studied how adults learnt in science-rich workplaces, which received the Outstanding Dissertation Award 2006 (by European Foundation for Management Development) and Outstanding Paper of the Year at the Emerald Literati Network Awards for Excellence 2006 in the Journal of Workplace Learning. Yew Jin was past co-editor of Pedagogies: An International Journal (Routledge) and serves on the editorial boards of Research in Science Education (till 2018), Studies in Science Education, and Asia-Pacific Science Education. He has performed international consultancy work with the Asian Development Bank, the World Bank, the Temasek Foundation (Singapore) as well as in various universities in the Asian region on matters of science education. In 2008/9, he received a Fulbright Academic Exchange award to study urban science education with the City University of New York while in 2013 he spent part of his sabbatical in Southern California with after-school centers catering for ELLs and migrant children.

His research interests include curriculum studies, classroom assessment, epistemic knowing and questions of knowledge, and learning in formal/informal work environments.

Appendix 4 – Seminar Agenda

Day 1, 23 Mar 2021, Tuesday

No.	Time (GMT+8)	Key Activity	Format*
1	0900h-0930h	Welcome address and overview of the seminar	VS
2	0930h-1030h	Sharing by the Project Overseers on the synthesis of the responses in the pre-seminar questionnaire followed by Question and Answer (Q&A)	VS
3	1030-1100h	Administer diagnostic survey to find out the participants' knowledge in STEM integration, model development, and gender-inclusivity	VA
4	1200-1300h	Invited Speaker's Talk + Q&A on Topic 1: *STEM Integration Models* *Name of Speaker:* Dr Lilia Halim, The National University of Malaysia (MAS)	VS
	1300-1400h	Facilitated small group discussions on Topic 1	VSBO
	1410-1600h	Reporting by breakout groups on key discussion points	VS
	1600-1630h	Consolidation of the key points discussed in Day 1 by the Project Overseers	VS

Day 2, 24 Mar 2021, Wednesday

No.	Time (GMT+8)	Key Activity	Format*
1	0900-0910h	Recap on Day 1 discussions	VS
2	0910-1010h	Invited Speaker's Talk + Q&A on Topic 2: *The Need for Gender-Inclusive STEM Education* *Name of Speaker:* Dr Sonya N. Martin, Seoul National University (ROK)	VS
	1015-1115h	Facilitated small group discussions on Topic 2	VSBO
	1120-1230h	Reporting by breakout groups on key discussion points	VS
3	1330-1430h	Invited Speaker's Talk + Q&A on *Topic 3: Curriculum Models for STEM* *Name of Speaker:* Dr Yew Jin Lee, National Institute of Education, Nanyang Technological University (SGP)	VS

No.	Time (GMT+8)	Key Activity	Format*
	1440-1600h	Facilitated small group discussions on Topic 3	VSBO
	1600-1700h	Reporting by breakout groups on key discussion points	VS
	1700h-1730h	Consolidation of the key points discussed in Day 2 by the Project Overseers	VS

Day 3, 25 Mar 2021, Thursday

No.	Time (GMT+8)	Key Activity	Format*
1	0900-0910h	Recap on Day 1 and 2 discussions	VS
2	0910-1100h	Facilitated small group discussions on Topic 4: *Develop a STEM course that is integrated and gender-inclusive*	VSBO
	1100-1130h	Reporting by selected breakout groups on key discussion points	VS
3	1230-1300h	Sharing of two case examples of pedagogies adopted for enacting integrated STEM courses by two economies' participants: • Dr Gillan Kidman, Monash University (AUS) • Dr Aik-Ling Tan, National Institute of Education Nanyang Technological University (SGP)	VS
	1315-1345h	Sharing of one case example of gender-inclusive assessment for integrated STEM tasks by one economy's participants: • Dr Paola Magni, Murdoch University (AUS)	VS
4	1345-1400h	Consolidation of key points discussed in Day 3 by the Project Overseers	VS
5	1400-1500h	Administer diagnostic survey (same instrument as Day 1) to find out the participants' knowledge in stem integration, model development, and gender-inclusivity	VS
6	1500-1530h	Closure of the seminar by the Project Overseers	VS

* VS = Virtual Synchronous (recorded sessions)
* VA = Virtual Asynchronous
* VSBO = Virtual Synchronous Breakout sessions (facilitated small group discussions)

The recorded sessions will be made available on the virtual event portal and accessible only to the seminar participants who are unable to participate in the VS sessions. The templates used to facilitate the VSBO sessions will be made available for their inputs.

Appendix 5a – Seminar Diagnostic Survey

The following instrument is a diagnostic tool related to the three topics of this project and seminar -- curriculum model, STEM integration and gender inclusivity.

Q1. Please provide your Full Name (First Name, Last Name)

Integrated STEM Education

Q2. Please respond to the following items:

#	**Statement**	**Strongly Disagree 1**	**Disagree 2**	**Neither agree nor disagree 3**	**Agree 4**	**Strongly agree 5**
1	I know the purpose(s) of an undergraduate STEM education.					
2	What we plan for STEM education will make the economy a better place.					
3	What we plan for STEM education will make the Universities a better place.					
4	I have thought about how my gender can influence my curriculum making.					
5	I have thought about how my experiences, can influence my curriculum making.					
6	I have thought about how my training can influence my curriculum making.					
7	I know the challenges in planning an integrated STEM degree program.					
8	I know the challenges in planning a gender inclusive STEM degree program.					
9	I am confident of implementing a gender inclusive STEM degree program.					
10	I am confident of implementing an integrated STEM degree program.					

Q3. Which of the following statement(s) has/have been used to define integrated STEM education? (You may select more than 1.)

- □ It involves two or more disciplines.
- □ It involves collaboration among individuals.
- □ It addresses problems that cannot be solved by one discipline.
- □ It addresses a real-world problem.
- □ It has a humanistic goal.

Q4. What are some other definition(s) or description(s) of integrated STEM education (that you know of but is/are) not mentioned in the previous item? Please write in the space below.

Q5. In your view, how is integrated STEM education different from other forms of non-integrated STEM education?

Q6. STEM lessons are oftentimes linked to solving real world problems. What characteristics should these problems fulfil? Please list 3 of these.

1. ____

2. ____

3. ____

Q7. What are some ways in which STEM content may be connected to form an integrated lesson?

1. ____

2. ____

3. ____

<u>Challenges to STEM Integration</u>

Q8. Which of the following are possible challenges to successful implementation of an integrated STEM curriculum at the University? (You may select more than 1.)

- ◻ Lack of collaboration across departments or colleges
- ◻ Resistance from faculty members
- ◻ Too much pride in one's discipline and training
- ◻ Lack of structures (e.g.,, policies on collaboration, recognition, rewards, etc.)
- ◻ Insufficient resources for integrative work
- ◻ Lack of knowledge of STEM integration among faculty members

Q9. What are some other challenges that are not listed above? Please write them down.

A STEM Educator

Q10. In comparison to a science, mathematics, engineering, or technology educator, a STEM educator is better in the following aspects:

#	Statement	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
		1	2	3	4	5
1	Able to solve more complex problems					
2	Equipped with more diverse teaching strategies					
3	A team player					
4	More adaptable					
5	Has deeper content knowledge of the discipline(s)					
6	Has broader content knowledge of the discipline(s)					
7	Address diverse students' needs					
8	More open to different perspectives					
9	Has stronger pedagogical knowledge					
10	Is Future-Ready					

#	Statement	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
		1	2	3	4	5
11	Able to integrate different disciplinary ideas					
12	More flexible in problem solving					
13	Able to solve more complex problems					

Gender Inclusivity

Q11 STEM programs can be more gender inclusive by:

#	Statement	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
		1	2	3	4	5
1	Enrolling more female than male students					
2	Creating more team based activities					
3	Adopt more participatory approaches					
4	Creating more open-ended than close-ended test items					
5	Arrange for more project work					
6	Creating problems just for female students					
7	Hiring more female STEM faculty					
8	Assign female STEM faculty as mentor to each female student					
9	Create flexible degree programs					
10	Offering elective courses that explicitly address gender issues					
11	Offering compulsory courses that explicitly address gender issues					

#	Statement	Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
		1	2	3	4	5
12	Foregrounding women's needs in solving STEM problems					
13	Having male and female role models					

Q12 I have strong feelings about teaching gender inclusivity in my courses.

- ☐ Strongly Disagree
- ☐ Disagree
- ☐ Neither Agree or Disagree
- ☐ Agree
- ☐ Strongly Agree

Appendix 5b – Data Collected from Pre-and Post-Seminar Diagnostic Surveys

The following instrument is a diagnostic tool related to the three topics of this project and seminar -- curriculum model, STEM integration and gender inclusivity.

<u>Integrated STEM Education</u>

Q2. Please respond to the following items:

#	Field	Mean Pre	Mean Post	Std Pre	Std Post
	I know the purpose(s) of an undergraduate STEM education.	4.40 *(N=15)*	4.67 *(N=9)*	0.71 *(N=15)*	0.47 *(N=9)*
2	What we plan for STEM education will make the economy a better place.	4.53 *(N=15)*	4.67 *(N=9)*	0.62 *(N=15)*	0.47 *(N=9)*
3	What we plan for STEM education will make the Universities a better place.	4.53 *(N=15)*	4.67 *(N=9)*	0.62 *(N=15)*	0.47 *(N=9)*
4	I have thought about how my gender can influence my curriculum making.	3.93 *(N=15)*	3.89 *(N=9)*	1.00 *(N=15)*	1.20 *(N=9)*
5	I have thought about how my experiences, can influence my curriculum making.	4.20 *(N=15)*	4.89 *(N=9)*	0.65 *(N=15)*	0.31 *(N=9)*
6	I have thought about how my training can influence my curriculum making.	4.27 *(N=15)*	4.89 *(N=9)*	0.68 *(N=15)*	0.31 *(N=9)*
7	I know the challenges in planning an integrated STEM degree program.	3.93 *(N=15)*	4.67 *(N=9)*	0.85 *(N=15)*	0.47 *(N=9)*
8	I know the challenges in planning a gender inclusive STEM degree program.	3.60 *(N=15)*	4.56 *(N=9)*	0.95 *(N=15)*	0.68 *(N=9)*
9	I am confident of implementing a gender inclusive STEM degree program.	3.47 *(N=15)*	4.44 *(N=9)*	0.88 *(N=15)*	0.68 *(N=9)*
10	I am confident of implementing an integrated STEM degree program.	3.73 *(N=15)*	4.33 *(N=9)*	1.00 *(N=15)*	0.67 *(N=9)*
	Overall Mean ***Overall Standard Deviation***	***4.06***	***4.57***	***0.80***	***0.57***

Q3 - Which of the following statement(s) has/have been used to define integrated STEM education? (You may select more than 1.)

#	Answer	Pre	Post
1	It involves two or more disciplines.	21.05%	21.95%
2	It involves collaboration among individuals.	21.05%	21.95%
3	It addresses problems that cannot be solved by one discipline.	26.32%	19.51%
4	It addresses a real world problem.	21.05%	19.51%
5	It has a humanistic goal.	10.53%	17.07%
	Total	100%	100%

Q4 - What are some other definition(s) or description(s) of integrated STEM education (that you know of but is/are) not mentioned in the previous item? Please write in the space below.

Pre	Post
The nature of the collaborations is important - integrated STEM will probably be best achieved across the academia-industry interface.	Includes individual semester course work that merges two disciplines (could be physics + biology or chemistry + math or chemistry + biology +physics + technology + computer science + math). Includes a full degree program that is designed with fully integrated courses and experiences.
It addresses problems of a global and competitive society, where borders between economies are diffuse. It is about connecting ideas across disciplines to solve problems creatively,	STEM consists of multiple learning and teaching pathways that converge into a dynamic outcome: solving a problem/issue that is functional, transferable, and expandable (something that can evolve in time) to a target audience/group.
I just suggest that multiple disciplines should be implemented in the class, lesson or programs thus, how about putting the word regarding this approach in the final statement? Also, how about considering the "connection between courses and a real-world context" through the integrated STEM education?	There is degree of integration to which disciplines are integrated in STEM: Transdisciplinary, Interdisciplinary, Multidisciplinary, Parallel Discipline, and Disciplined Based.
It encourages students' passions and creativity.	Provide a creative solutions or outcome to resolve the problem in real world and regional society.
Grapples with topics that involve common themes (ie complexity science) and methodologies (ie quantitative methods) across disciplines. Has no disciplinary advantage (that is, cohorts of students are not advantaged or disadvantaged - ie, through numerical exams or other disciplinary practices) is generative - in my interdisciplinary courses, the 'problem' is generally known, but the 'solutions' are not. These are generated with the students. A focus on process not outcome.	It is a hybrid curriculum
Interdisciplinary. Students learn the practice and process of science rather than a focus on specific disciplinary STEM knowledge.	transdisciplinary and transcendent knowledge building/creation
Problem solving process to resolve the problem mixed with several knowledge.	

Pre	Post
needs to go beyond muti inter and cross disciplinary and aim for transdisciplinary integration. The learning needs to transcend what is learnt from a single or multiple discipline, and this is characterised by the thinking involved.	
transdisciplinary - it goes beyond collaboration to an integration of cognitive abilities across disciplines which also improves metacognition in our graduates. Applied.	
It is about developing 21st CC on top of disciplinary knowledge.	
The above (all options) cover most everything.	

Q5 - In your view, how is integrated STEM education different from other forms of non-integrated STEM education?

Pre	Post
Higher cost efficiency resulting from synergy created from integrated teaching and learning.	Based on what we discussed this week, integrated STEM includes elements of science, technology, engineering and math as distinct separate disciplines. However, based on previous knowledge and experience in my economy, integrated STEM could also include elements of disciplines within Science (but not TEM) or integration of different fields in Engineering but not (STM). The key elements we discussed this week include a focus on collaboration, problem-based or challenge-based learning, an emphasis on purposeful curricular integration, recognizing the importance of gender inclusivity. Non-integrated STEM education programs may include these elements listed above but may not be holistically and intentionally designed with all of the elements.
Not really, it should be addressed horizontal and holistically	The STEM education provides a strong and broad touch-base (non-linear) right at the beginning of the educational process; non-integrated is progressively linear.

Pre	Post
Greatest difference is the perspective. Traditional (non-integrated) STEM education focuses on technical depth and within-discipline accomplishment. This is undoubtedly important but integrated STEM, delivered to solve real-world problems, will bring greater motivation to achieve those accomplishments and better align with students' career goals.	In STEM education there is a lead discipline as the focus that is connected and related to the other three in different degrees.
Non-integrated STEM education focuses on improving learning of science, technology, engineering and mathematics as isolated spheres, within a pedagogical perspective that does not promote connection with creativity, design and prototyping as with real-world collaborative problem solving. Content is often managed by a single educator, struggling to make cross STEM connections. Integrated STEM Education promotes Co-teaching and the perfect balance within a context provided by engineering and technology, where engagement with science and mathematics is promoted.	All of students independent to their majors, deal with open topics or issues, team work and collaboration with other students of different major. especially engineering and non-engineering students
emphasizing the connection between a classroom and the STEM practices in authentic context	Inter/multi/transdisciplinary in its design.
More than just a cut-and-sry approach, an integrated STEM education contextualizes what one is learning in a social backdrop and encourages an intersectional angle rather than a single-minded one.	The transdisciplinary and transcendent aspects are not as easily achieved in non-integrated programs.
It better prepares students for the real world which is not integrated or understood in silos.	The collaborative work is the most important one.
Integrated STEM education considers that learning and doing STEM are not done in a vacuum. The experiences before students start at university and after the leave and join the workforce as also important. Integrated STEM education also examines who participates in STEM education and in the workforce (for example are there populations of students underrepresented--women, students from lower socioeconomic backgrounds, etc.)	It is more holistic

Pre	Post
It is a process in which people with different knowledge come together to find a solution about the same problem .	
Mathematics is a tool that can be applied and helped to solve a lot of problems.	
It is in the type of thinking. STEM integrative thinking can lead to transcendence in learning far more easily than say scientific thinking or mathematical thinking etc. STEM needs to be considered as a type of thinking not just the integration of disciplines.	
It enables greater integrative knowledge in graduates - potentially making them more employable. It enables greater demonstration of the interaction between disciplines and their application. Promotes global citizenship.	
It is more holistic and complete.	
Non-integrated STEM education programs provide education and training in streams. Offer individual coursework. Maybe some collaborative practical coursework. I would assume an integrated program would attempt to address content learning from a systems connected and overlapping perspective. Like Biotechnology courses, etc.	

Q6 - STEM lessons are often times linked to solving real world problems. What characteristics should these problems fulfill? Please list 3 of these.

Pre-

1	2	3
targeted	well budgeted	free of gender biases
Open-ended	Requires innovation	Engage multitude of stakeholders

1	2	3
Real world problems are not well defined within an area of expertise.	Real world problems cannot be approached by looking for a right answer	Real world problems are dynamic and changes over time, so solutions may remain open and flexible
should be "purposely" designed to learn contents in STEM subjects	should be providing the manageable challenges or barriers by students	should be attractive and innovative to motivate students
Real world use cases	Practicality	Creativity
Discovery-based	No right answers	Generative outputs
critical thinking to take separate ideas and find the connections	understanding perspectives from different stakeholders	learning how to work both independently (to think, research, write) and collaboratively to look for solutions (and identify more challenges)
Can be resolved within a limited time	To be able to come up with a positive solution.	It should be a problem that participants can solve.
Numerical analysis	Statistical problems	Operations research
local\community or global\sponsored	projects	
be of student interest	relate to a problem that has many solutions	be interactive (hands on) and end with a student action
SUSTAINABILITY	Magnitude (global impact)	transdisciplinary
Complex	Persistent	Have real-world relevance
Improving society	Be sustainable	Address needs of many people

Post-

1	2	3
Instructors should create learning experiences for students to tackle problems that do not have easy, simple solutions (wicked problems or Ill-defined problems) and design novel solutions.	Instructors should create learning experiences for students to work collaboratively with their fellow students which allows for practice of communication and problem-solving skills.	Instructors should create learning experiences for students where the learning goals and objectives for solving real world problems are clear, assignments are designed transparently, and assessments are well-aligned to learning goals and objectives to measure student learning in the collaborative, innovative problem solving (beyond memorization for low-cognitive level exams).
complex	open-ended	time bound
Reflexivity	Flexibility	Relevance
Compelling purpose	Connected to the community of the students	Help students see both opportunities for themselves in STEM Careers, in how STEM disciplines can impact their lives.
positive direction	gender inclusivity	interdisciplinary of collaborable (My opinion)
Complex	Not a single answer/solution	Doable and interesting
team based	improve the already achieved	personally relevant
critical thinking	communication	find the appropriate technologies / solution in solving the challenges
Complex	Persistent	relevant

Q7 - What are some ways in which STEM content may be connected to form an integrated lesson?

Pre-

1	2	3
Analysis of curriculum	Lesson study among teachers across subjects	Thematic project
working with teachers in classrooms	interdisciplinary work	concrete examples and case studies
Emphasis on problem solving from early	Promote cross-subject relevance to prevent knowledge confined in silos	Extensive industry engagement to maintain relevance
Using engineering and technology to establish the context of the lesson	Looking for previous knowledge from science with literature reviews	Using Mathematics, to deliver and build models.
Project-based	Design thinking	backward design (identify the results desired (big ideas and skills) determine acceptable evidence design a STEM lesson implementing a STEM lesson)
Inter disciplinary courses	Creative one time projects	External speakers to provide real world inspiration
through common themes	through common problems	through interstitial topics (ie First Nations knowledge, Big History)
process of science through research experiences for all students	identifying cross-cutting concepts that students can explore from different perspectives (for example patterns or cause and effect models used to solve STEM questions across fields)	identifying key content that appears in different fields (for example rather than just learning calculus, learning how to calculate population growth curves or applying to other specific domains)
two or more professors	Participation of industry experts	Getting ideas from students

1	2	3
by defining the problems in a mathematical term to easen the analysis		
Through the context of the problem	Through the nature of the interactions demanded of the student	Through the challenge of requiring the student to 'act'.
Case studies from multi-disciplinary teams	Teachers from multi-disciplinary teams	Deliberate learning outcomes designed to integrate across disciplines
commonalities of conceptual knowledge	Skills across disciplines	Competencies such as media literacy, technology literacy etc
Application of mathematics in problem solving in content areas	Identifying different disciplinary connections to content needed for solving problems	Connecting STEM content to lives / concerns of students and society

Post-

1	2	3
View the same problem from multiple disciplinary perspectives (e.g., how does an ecologist or a hyro-engineer approach a water project)	Identify technology that can aid in learning a particular concept (e.g., parametric analysis to measure the efficacy of a building design or python for bioinformatics analysis of data)	Well-written learning goals and outcomes aligned with the assessments and a focus on the classroom activities that bridge the outcomes to assessments. This allows instructors to ensure that they have connected and integrated the content (purposefully left vague here) across all aspects of lesson design.
self-study modules	case studies	reflections
Contents can be connected in a spiral way	Integrative-thematic way	
Focus on connections between the disciplines (horizontal connections)	Vertical learning with a lead discipline	Problem solving, project based approach, active learning.

1	2	3
Transdisciplinary	Interdisciplinary	Parallel
Thematic	Problem based	Project Based
hands on	problem based	personally relevant
basic skills - computational thinking, design thinking	the multi-disciplinary collaboration	Communication
Using cases	Using problems	Design improvement

Challenges to STEM Integration

Q8 - Which of the following are possible challenges to successful implementation of an integrated STEM curriculum at the University? (You may select more than 1.)

#	Answer	Pre	Post
1	Lack of collaboration across departments or colleges	21.54%	16.28%
2	Resistance from faculty members	13.85%	13.95%
3	Too much pride in one's discipline and training	10.77%	13.95%
4	Lack of structures (e.g.,, policies on collaboration, recognition, rewards, etc.)	20.00%	20.93%
5	Insufficient resources for integrative work	15.38%	16.28%
6	Lack of knowledge of STEM integration among faculty members	18.46%	18.60%
	Total	***100%***	***100%***

Q9 - What are some other challenges that are not listed above? Please write them down.

Pre	Post
Wider industrial policies may not provide sufficient incentive to promote industry-academia collaborations	*Lack of administrative support (literally the Associate Deans, Deans, or Vice Presidents who would need to champion such efforts). *Lack of physical space for classes and labs to

Pre	Post
	meet. *Lack of understanding specifically what it means to have an "integrated STEM" program (e.g., must it include all of S, T, E, and M to technically be recognized as an integrated program? What if it only has multiple S disciplines...will integrated STEM champions elsewhere look down upon this effort? Perhaps it's better to have a more specific definition of a program for example "Integrated BioEngineering")
In the case of Mexico, the main challenge is the decision to invest resources and time to design the first curricular contents and pilot them, identifying the areas of opportunity and the need to migrate from traditional practices to address current challenges with STEM.	The current structures are designed around traditional disciplines, which makes it challenging to uncover.
Similar to pride, a black and white binary of what is “good” and “bad” STEM education, with the “good” fitting into the traditionally masculine cut-and-dry STEM curriculum.	Non-existence of transitional support to STEM integration
Lack of examples where this is done well. Fixation on siloed university structures Administration leading academic practice	How much funds are allocated to inter and transdisciplinary projects Reward Academia loyal to their discipline Not having Disciplinary Humility
Lack of understanding ways in which early pre-requisite courses impact future disciplinary specific work.	Active participation of administrative staff
Insufficiency of the university's administrative system	Financial support for the project
Societal beliefs or trust. Some people do not trust the post tertiary job market that employment from an integrated degree will lead to employment. A double degree is recognized, but not an integrated degree. Societal views needs addressing.	industry not realizing the graduate's potential
Enough individuals who research in multidisciplinary teams that also teach	Knowledge and competencies of faculty. Resources support Assessment

Pre	Post
Criteria for promotion and tenure of faculty members. The tradition idea of a specialist or expert in a narrow field is a stumbling block for faculty to be engaged in interdisciplinary work.	
This list seems exhaustive	

A STEM Educator

Q10 - In comparison to a science, mathematics, engineering, or technology educator, a STEM educator is better in the following aspects:

#	Field	Mean Pre	Mean Post	Std Pre	Std Post
1	Able to solve more complex problems	4.20 *(N=15)*	3.89 *(N=9)*	0.98 *(N=15)*	1.10 *(N=9)*
2	Equipped with more diverse teaching strategies	4.00 *(N=15)*	4.22 *(N=9)*	0.97 *(N=15)*	0.92 *(N=9)*
3	A team player	3.87 *(N=15)*	4.22 *(N=9)*	0.88 *(N=15)*	0.92 *(N=9)*
4	More adaptable	4.07 *(N=15)*	4.44 *(N=9)*	0.93 *(N=15)*	0.96 *(N=9)*
5	Has deeper content knowledge of the discipline(s)	3.00 *(N=15)*	3.33 *(N=9)*	0.89 *(N=15)*	1.05 *(N=9)*
6	Has broader content knowledge of the discipline(s)	3.93 *(N=15)*	3.78 *(N=9)*	0.77 *(N=15)*	1.13 *(N=9)*
7	Address diverse students' needs	3.80 *(N=15)*	4.22 *(N=9)*	0.91 *(N=15)*	0.92 *(N=9)*
8	More open to different perspectives	4.07 *(N=15)*	4.22 *(N=9)*	0.77 *(N=15)*	0.92 *(N=9)*
9	Has stronger pedagogical knowledge	3.80 *(N=15)*	4.22 *(N=9)*	0.91 *(N=15)*	0.92 *(N=9)*
10	Is Future-Ready	3.93 *(N=15)*	4.22 *(N=9)*	0.85 *(N=15)*	0.92 *(N=9)*
11	Able to integrate different disciplinary ideas	4.29 *(N=14)*	4.33 *(N=9)*	0.80 *(N=14)*	0.94 *(N=9)*
12	More flexible in problem solving	4.21 *(N=14)*	4.44 *(N=9)*	0.86 *(N=15)*	0.96 *(N=9)*
	Overall Mean	***3.93***	***4.13***		
	Overall Standard Deviation			***0.88***	***0.97***

Gender Inclusivity

Q11 - STEM programs can be more gender inclusive by:

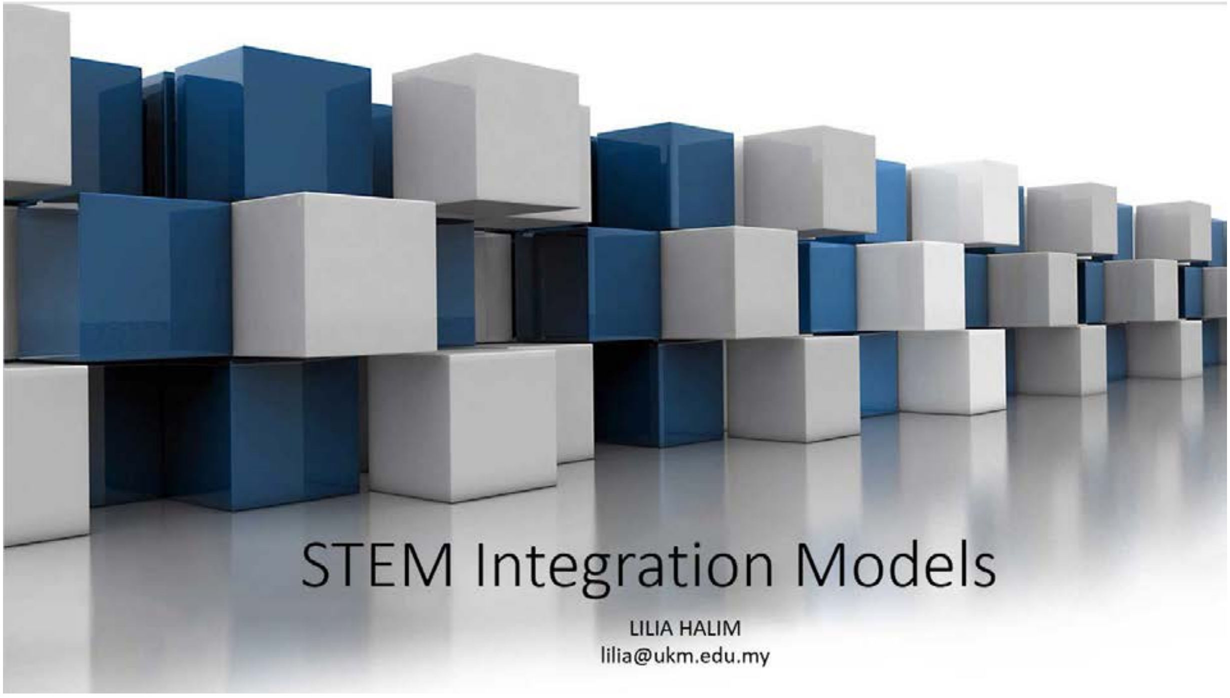
#	Field	Mean Pre	Mean Post	Std Pre	Std Post
1	Enrolling more female than male students	3.71 *(N=14)*	3.63 *(N=9)*	1.03 *(N=14)*	0.99 *(N=9)*
2	Creating more team based activities	4.36 *(N=14)*	4.44 *(N=9)*	0.61 *(N=14)*	0.50 *(N=9)*

#	Field	Mean Pre	Mean Post	Std Pre	Std Post
3	Adopt more participatory approaches	4.50 *(N=14)*	4.67 *(N=9)*	0.50 *(N=14)*	0.47 *(N=9)*
4	Creating more open-ended than close-ended test items	4.21 *(N=14)*	4.44 *(N=9)*	0.77 *(N=14)*	0.50 *(N=9)*
5	Arrange for more project work	4.07 *(N=14)*	4.22 *(N=9)*	0.80 *(N=14)*	0.63 *(N=9)*
6	Creating problems just for female students	2.50 *(N=14)*	2.78 *(N=9)*	0.91 *(N=14)*	0.63 *(N=9)*
7	Hiring more female STEM faculty	4.21 *(N=14)*	4.11 *(N=9)*	0.77 *(N=14)*	0.74 *(N=9)*
8	Assign female STEM faculty as mentor to each female student	3.71 *(N=14)*	4.22 *(N=9)*	0.70 *(N=14)*	0.79 *(N=9)*
9	Create flexible degree programs	4.07 *(N=14)*	4.56 *(N=9)*	0.70 *(N=14)*	0.50 *(N=9)*
10	Offering elective courses that explicitly address gender issues	3.79 *(N=14)*	4.00 *(N=9)*	0.86 *(N=14)*	0.47 *(N=9)*
11	Offering compulsory courses that explicitly address gender issues	3.43 *(N=14)*	3.56 *(N=9)*	0.90 *(N=14)*	1.26 *(N=9)*
12	Foregrounding women's needs in solving STEM problems	4.07 *(N=14)*	4.22 *(N=9)*	0.70 *(N=14)*	0.63 *(N=9)*
13	Having male and female role models	3.77 *(N=13)*	4.44 *(N=9)*	1.12 *(N=13)*	0.68 *(N=9)*
	Overall Mean ***Overall Standard Deviation***	***3.88***	***4.10***	***0.80***	***0.68***

Q12 - I have strong feelings about teaching gender inclusivity in my courses.

#	Field	Mean Pre	Mean Post	Std Pre	Std Post
1	I have strong feelings about teaching gender inclusivity in my courses.	3.77 *(N=13)*	4.22 *(N=9)*	0.80 *(N=13)*	0.92 *(N=9)*

Appendix 6 – STEM Integration Models by Dr Lilia Halim



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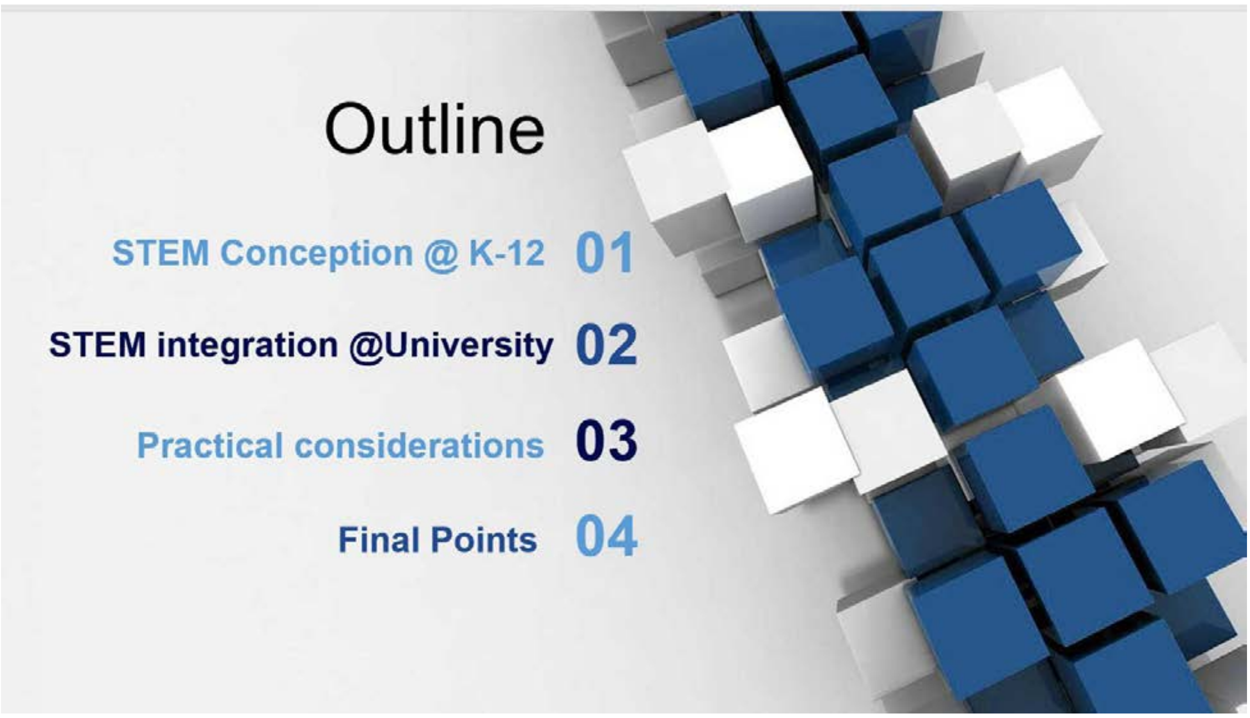

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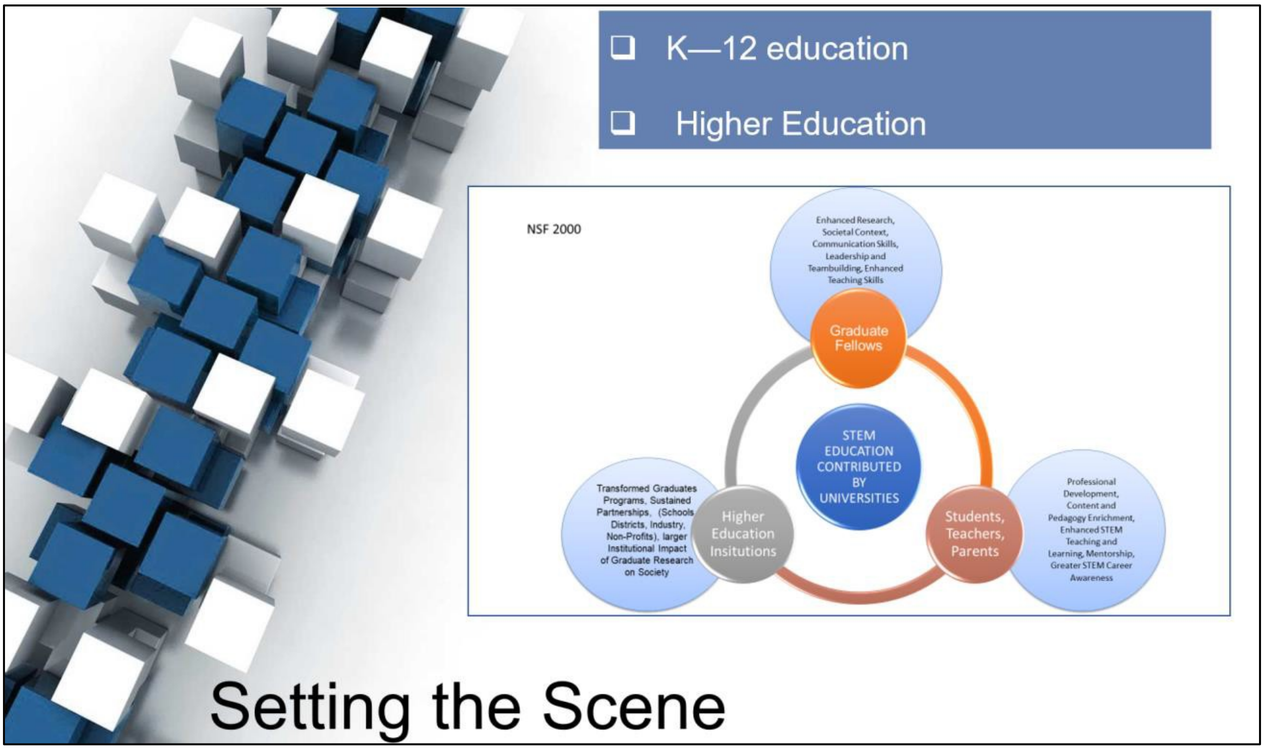

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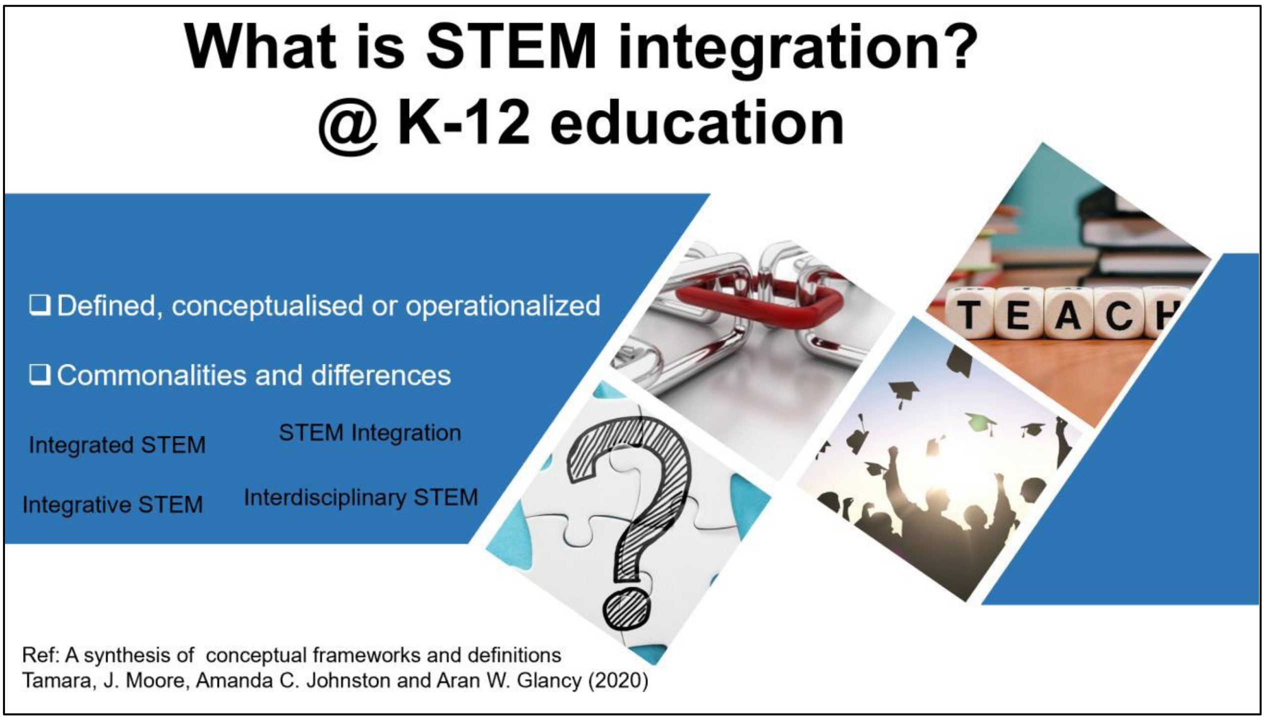

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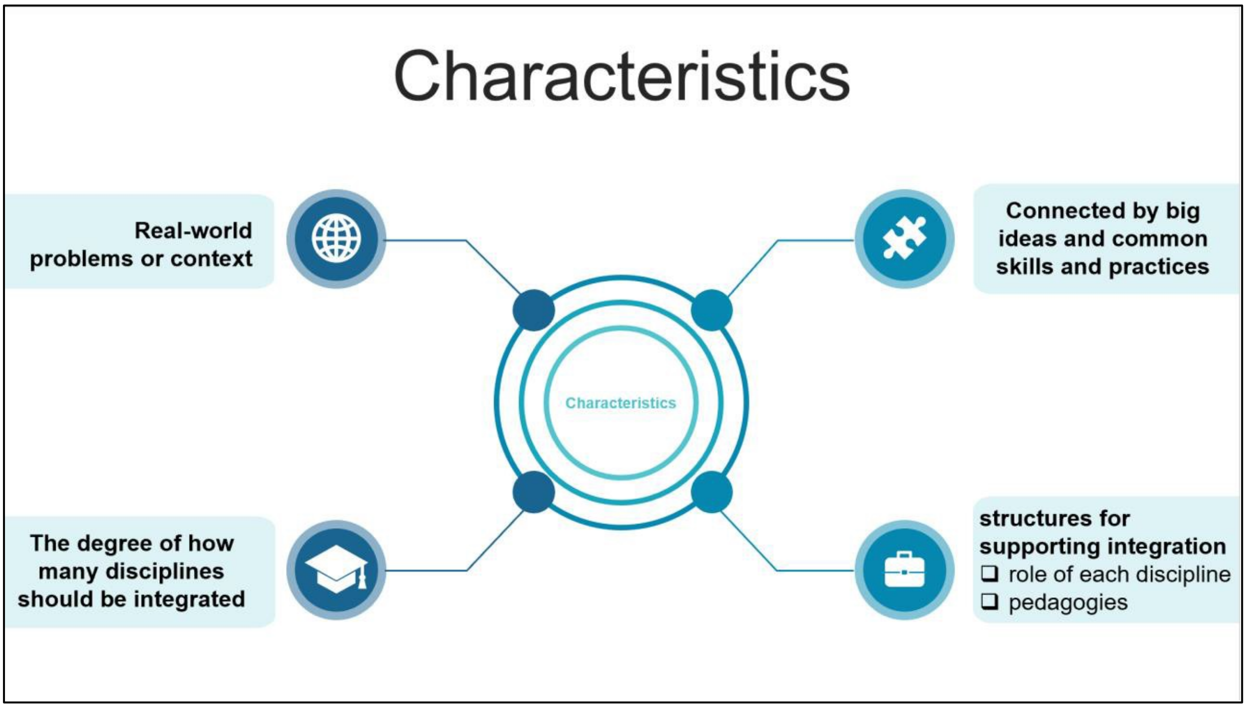

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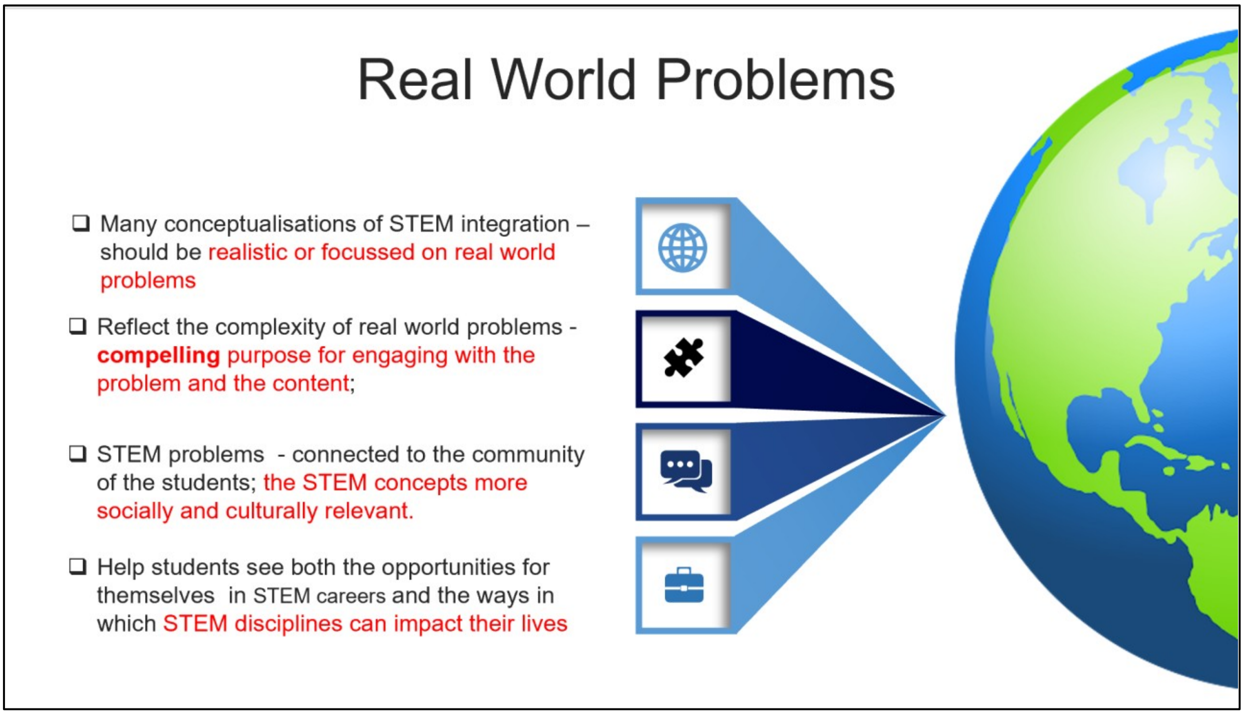

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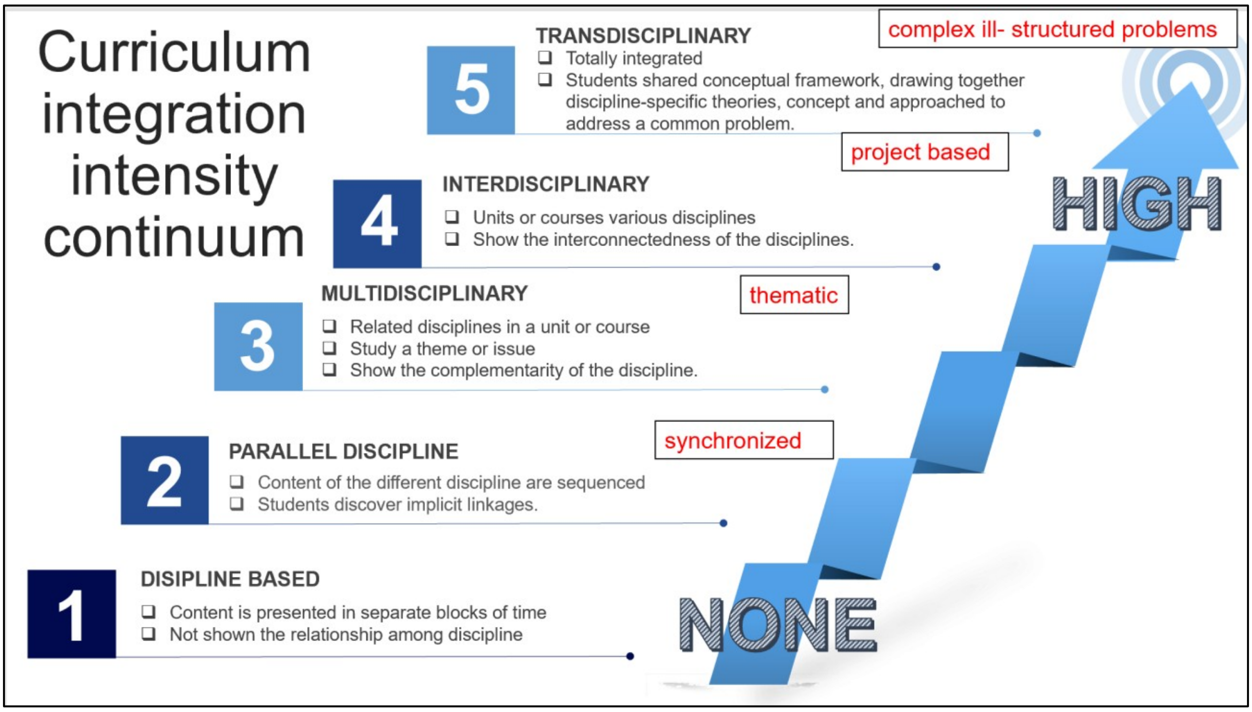

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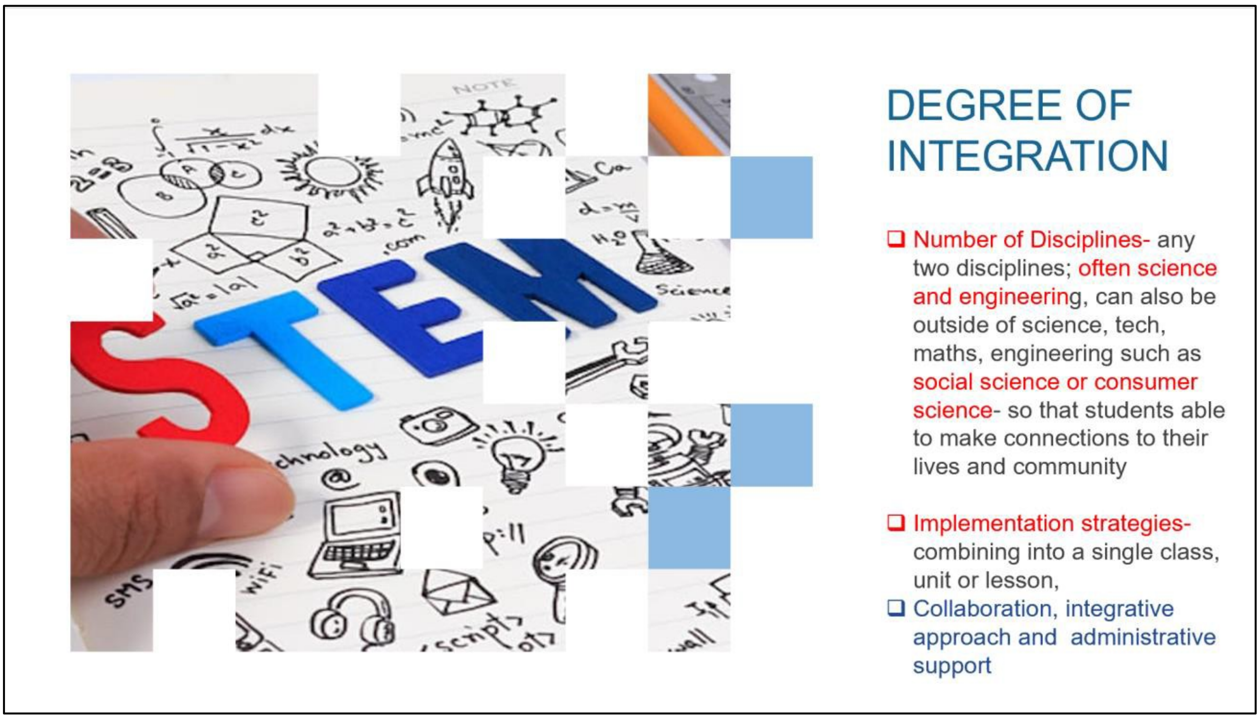

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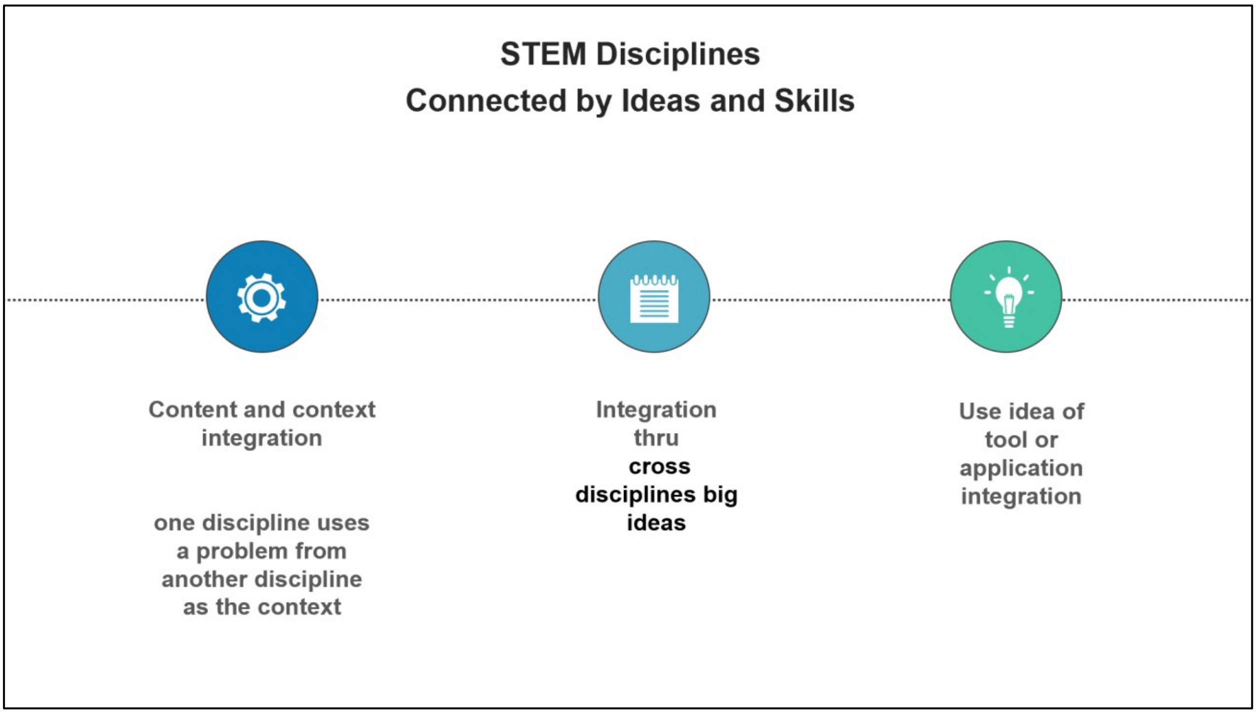


Slide 9

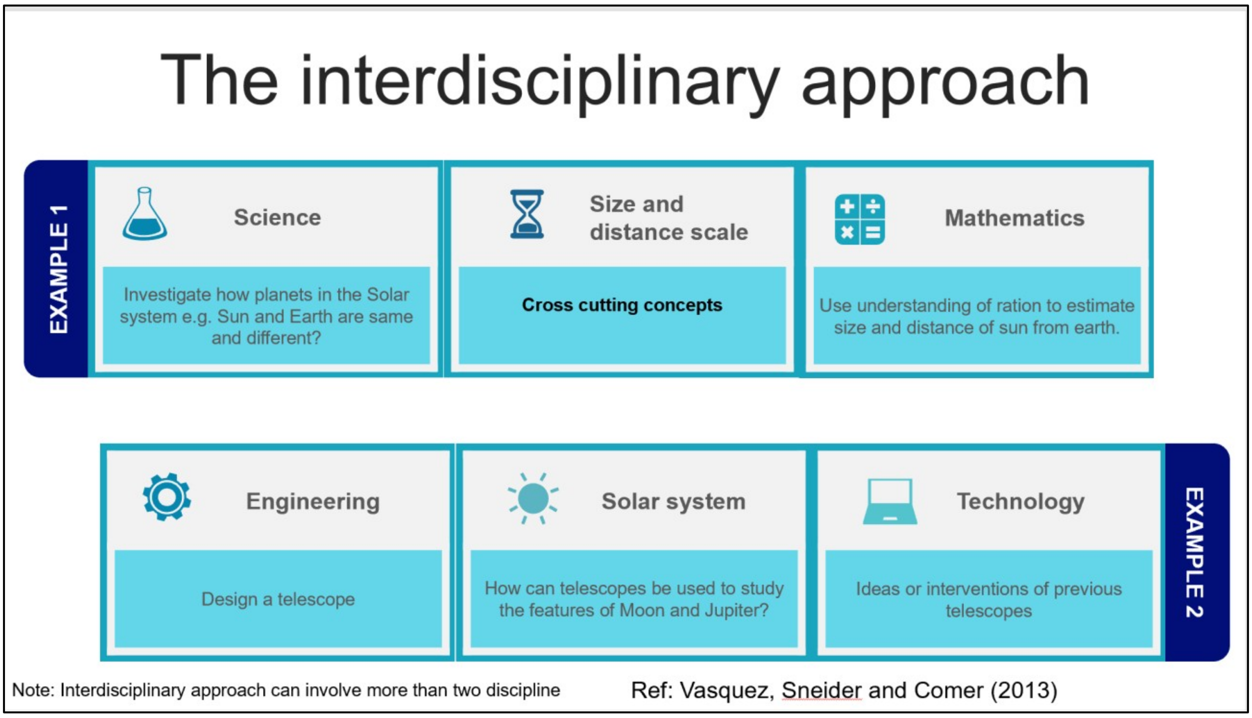
Role of content (primary, supporting or absent)

Role of context (disciplinary contexts background contexts) e.g. societal or historical issues

Content	Science	Technology	Engineering	Mathematics	Arts
Primary			x	x	
Supporting	x				
Context disciplinary		x	x		
Backgroud	Personal	Societal	Occupational	Historical	Others

Sample of STEM integration matrix
Source: English (2017) pg.4

Slide 10

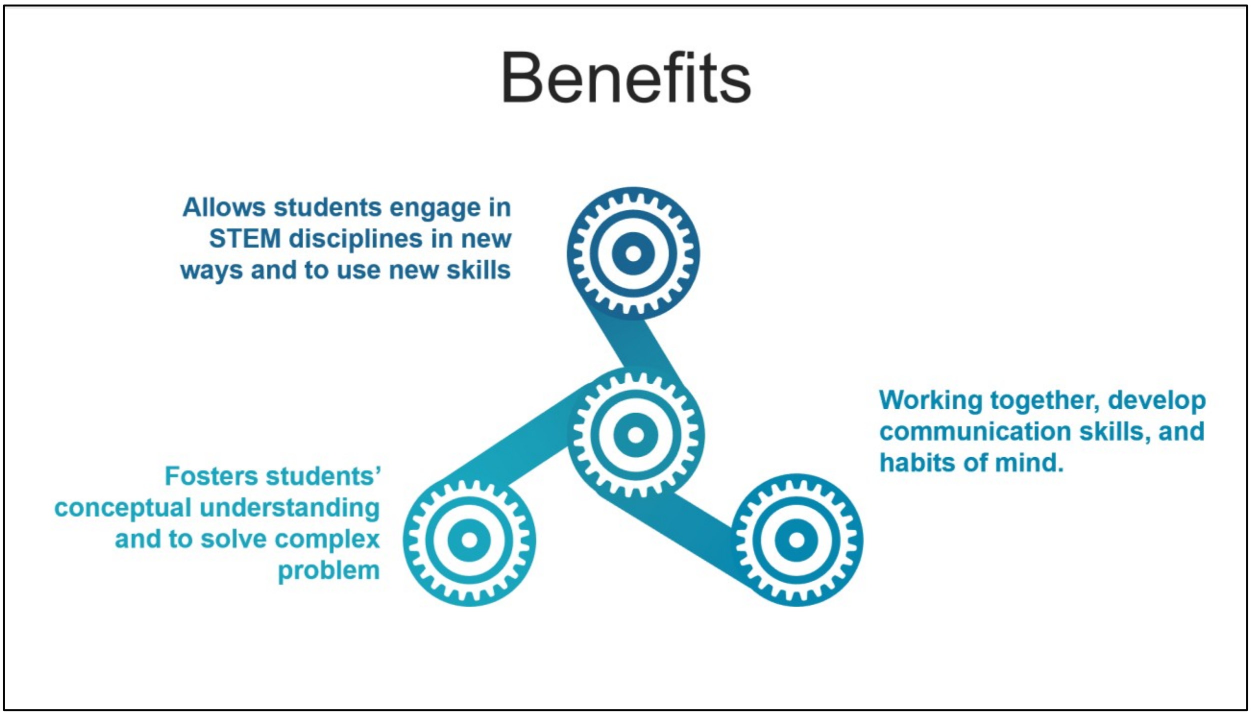


Slide 11

Context	Science	Engineering	Mathematics
Design a solar car that moves the furthest and in a straight line.	Fleming's left hand rules, Friction force, normal force, external force	Engineering design process	Illuminating angle Ratio
Determine if a gold crown is real or fake	Mass, Volume and Density	NA	Slope and analysis of graphs
Design a kite	-NA	Engineering design process	Scale drawings Concepts of parallelograms

Source: Adapted from Stohlmann, Roehrig and Moore (2014) pg. 20

Slide 12



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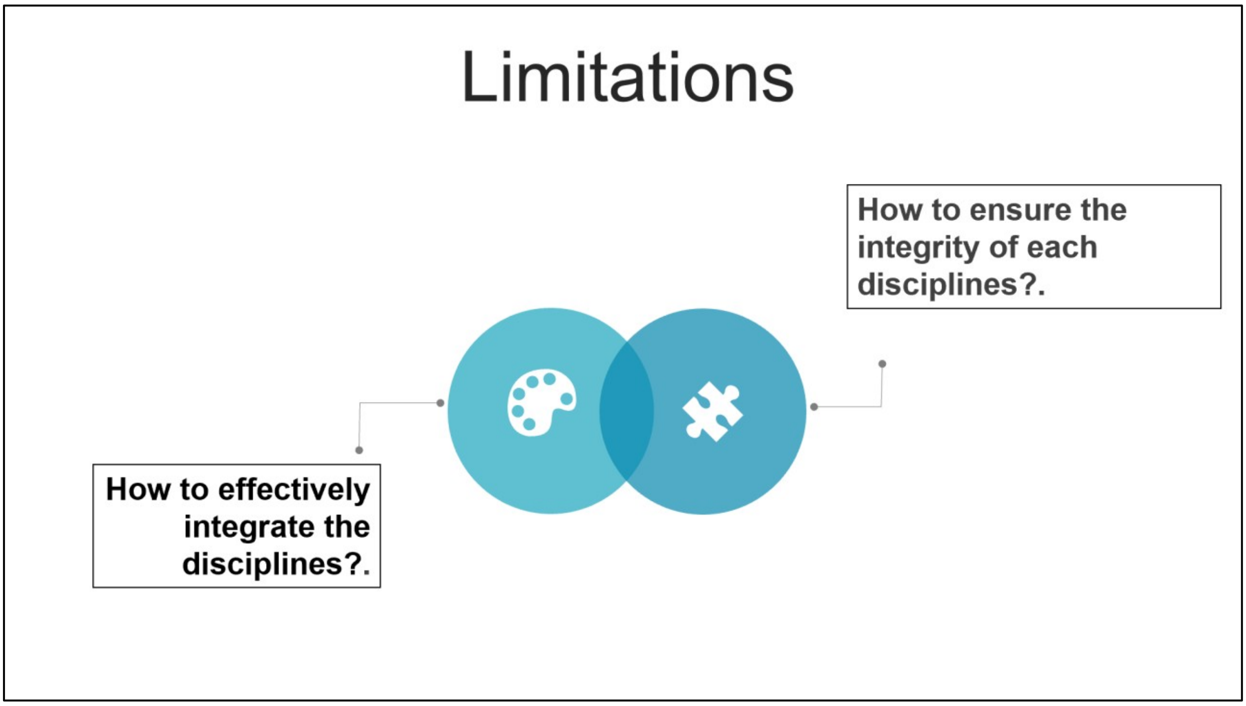

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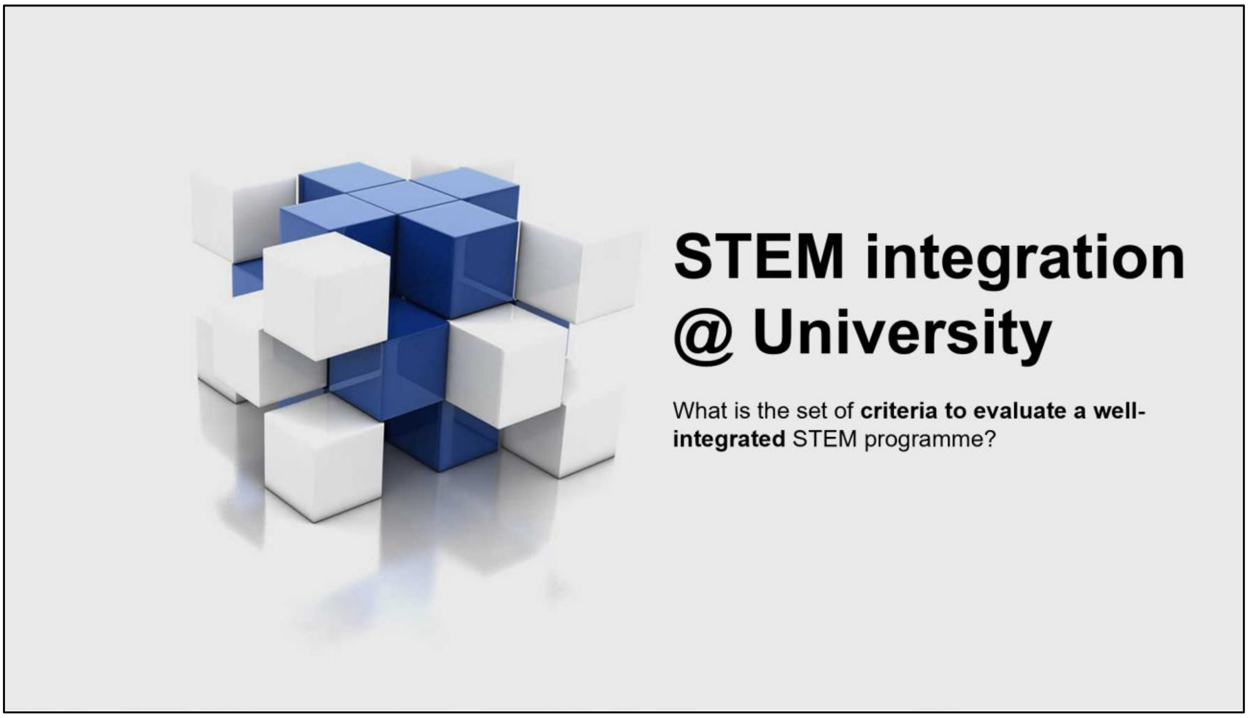

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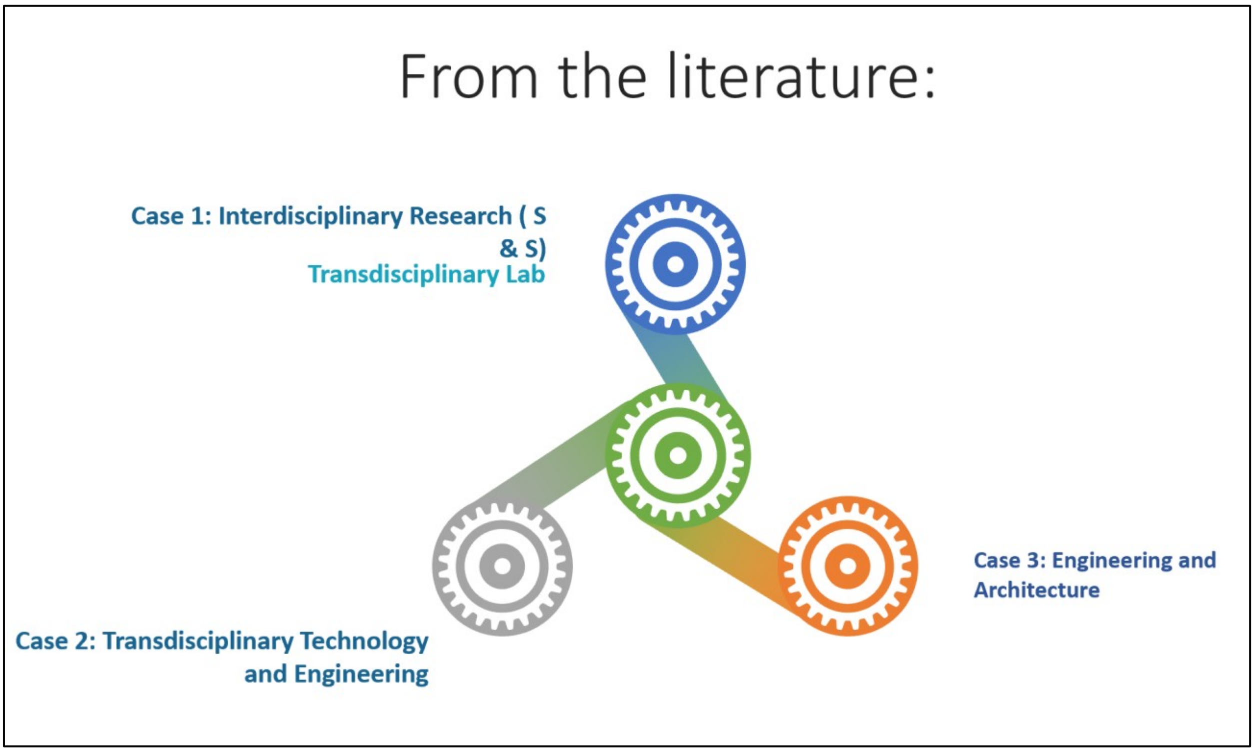


Slide 16

Slide 17

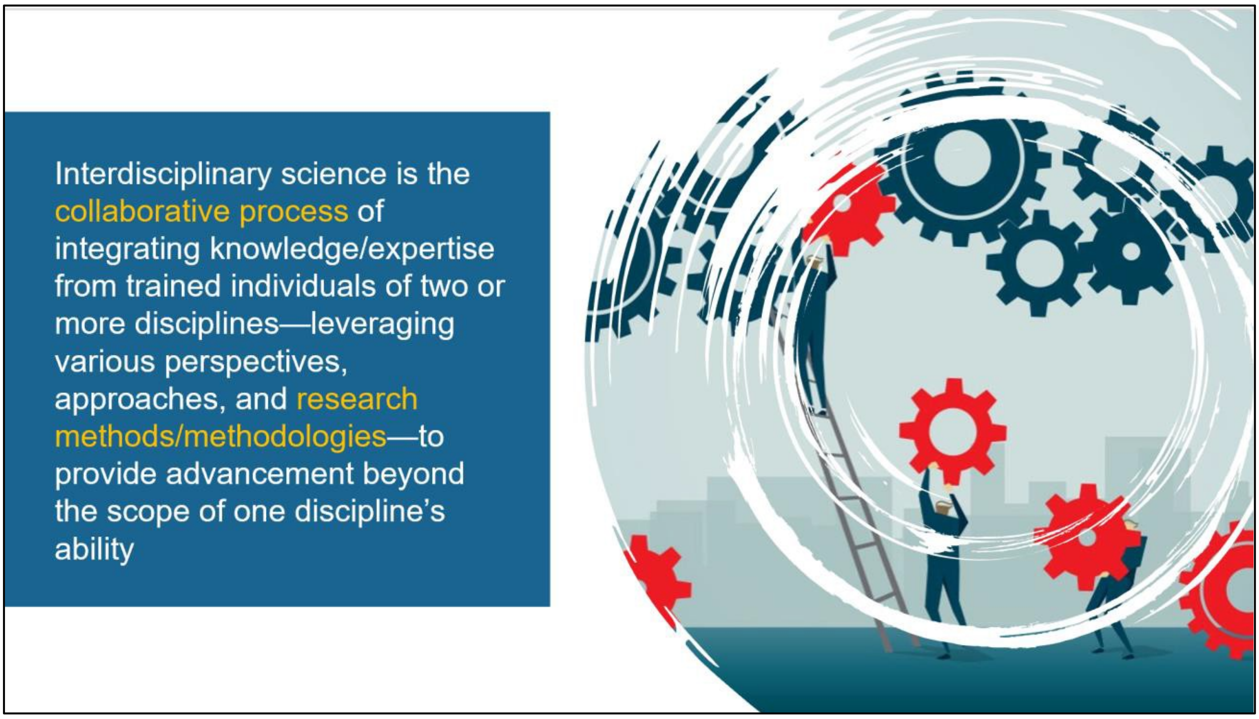
TABLE 1. Top six emergent themes from surveyed science faculty ($n = 184$) on how they define interdisciplinary science[a]

Top themes among interdisciplinary science definitions	*n*	%[b]
Involves two or more disciplines	173	94.0
Use of multiple/differing research methods/ methodology	79	43.0
Collaboration among individuals	52	28.3
Need for other/additional disciplinary knowledge/ expertise	52	28.3
Having various perspectives, theories, approaches	48	26.1
Addresses problems that cannot be solved by one discipline	37	20.1

[a]Interrater reliability of greater than 80% was obtained.
[b]Themes do not add up to 100%, as individuals made statements that were coded to multiple themes.

Tripp, B., & Shortlidge, E. E. (2019).

Slide 18



Slide 19

Case 1: This study was approved by Portland State University's

Does your course have learning outcomes related to students' understanding of the interdisciplinary nature of science ?

"How we can better support faculty to create and embed learning outcomes related to interdisciplinary science for undergraduates?"

Slide 20

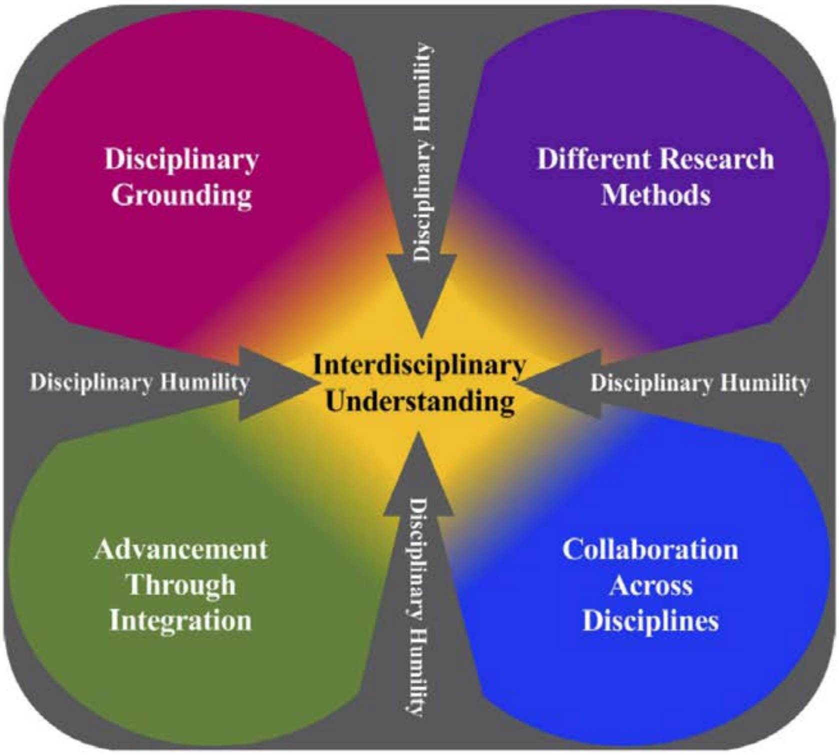


FIGURE 1. Interdisciplinary Science Framework (IDSF) for guiding students to tap into the interdisciplinary nature of science.

Ref: Portland State University's

Tripp, B., & Shortlidge, E. E. (2019).

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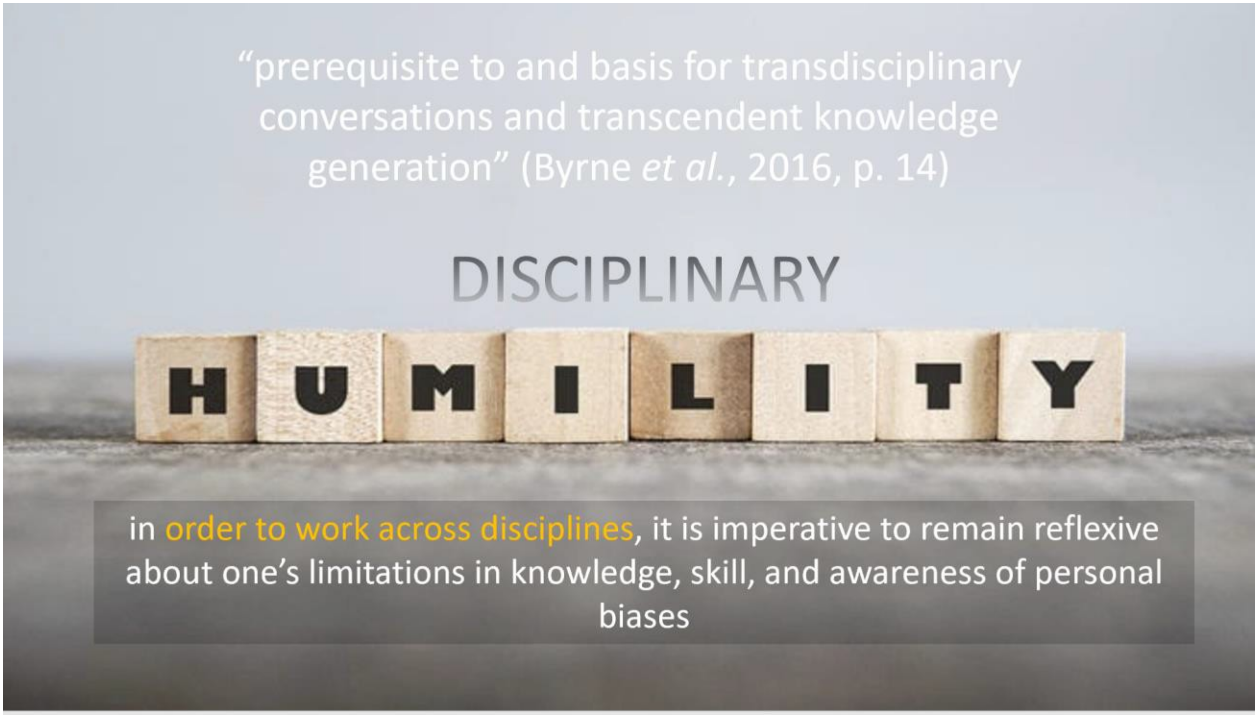

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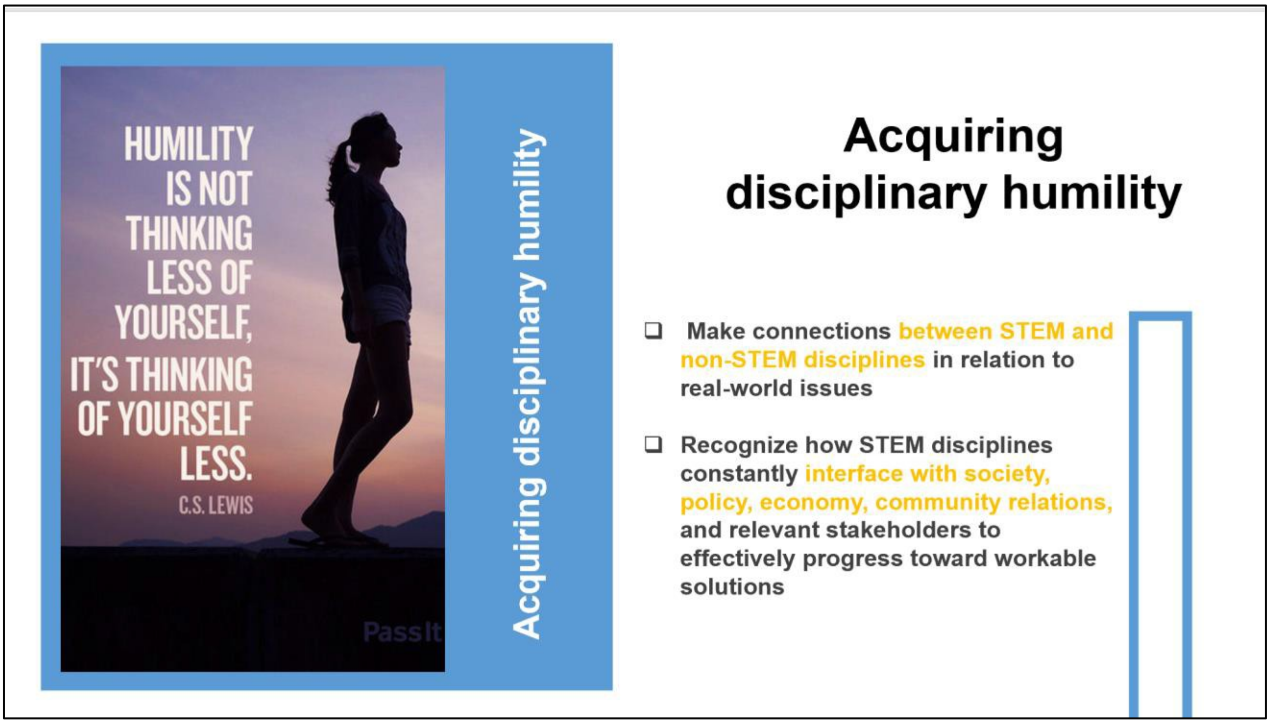

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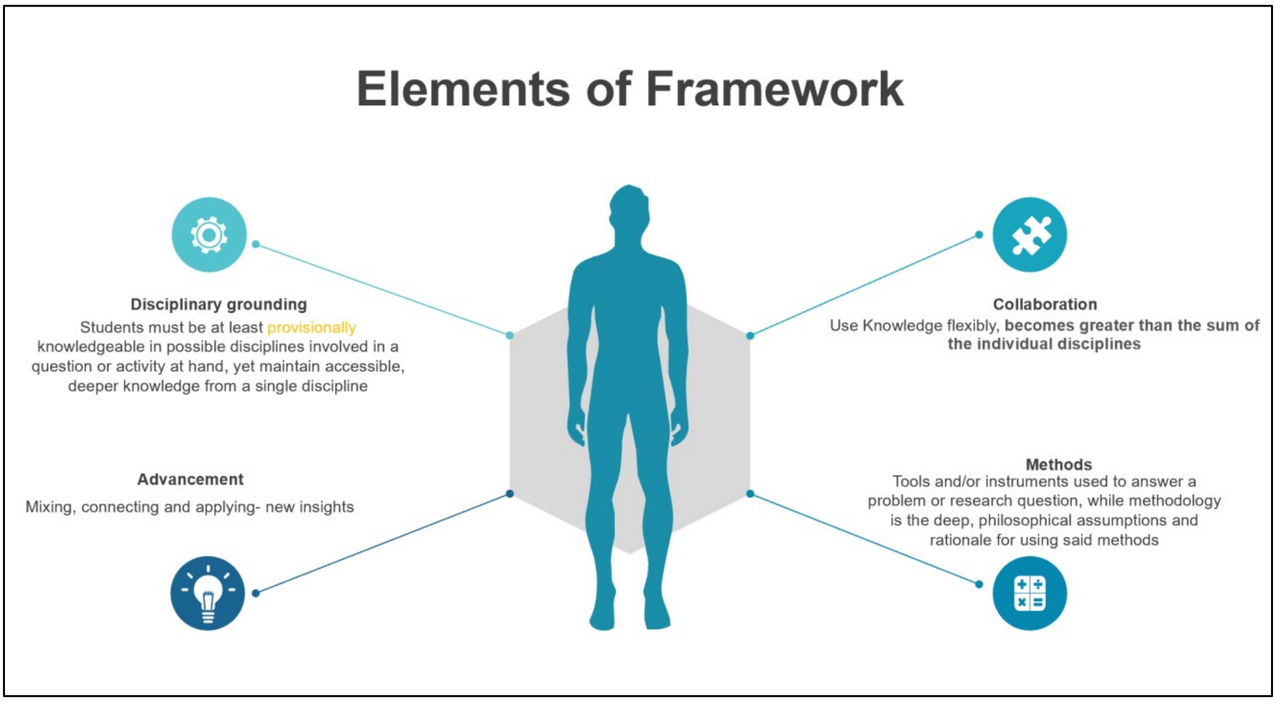

Slide 24

Declining honeybee populations

Example of using the framework

Address the problem

Students could be assigned to groups of six and tasked with identifying what disciplines may need to be involved to fully address the problem of declining honeybee populations.

Assign disciplinary roles to one another

Next, students could assign disciplinary roles to one another, representative of the disciplines needed to tackle the problem, such as: an agronomist, an entomologist, an evolutionary biologist, an organic chemist, a climatologist, and an anthropologist.

Independently research the discipline

Students then independently research the discipline they are assigned as it relates to the issue.

Reconvene to collaboratively discuss relevant disciplinary

Students reconvene to collaboratively discuss relevant disciplinary knowledge and what research methods to use and why, as well as the limitations of their disciplinary role.

Slide 25

18:es3, 10

B. Tripp and E. E. Shortlidge

TABLE 3. Example curriculum applying the IDSF to an interdisciplinary course assignment: Students in an upper-division environmental course are tasked to address the decline in honeybee populations via an activity and assignment in which they are asked to construct a proposal to mitigate this issue and are scored on the inclusion of the five IDSF criteria in their response

IDSF CRITERIA	**Learning Goal:** What should students know, understand, and be able to do at the end of the course/ task? **Students will:**	**Learning outcome:** How will I determine whether students have met this learning goals? **Students will:**	**Activities:** What exercises will engage a diverse group of students in learning? **Deliberative Democracy Activity (DD)** **Students will:**	**Assessments:** What assessments will effectively gauge if learning goals are met?	**Alignment:** Do the activities and assessments help students achieve the learning goals?
Disciplinary Humility	Appreciate how the union of disciplines can add greater understanding and that disciplines acting alone have limitations	Consider the limitations of one discipline Highlight the benefits multiple disciplines have on real-world issues Include disciplines outside STEM and connections to society	Research limitations of their role in relation to issue Independently identify why other's roles are necessary Connect issue to society	**FORMATIVE** Case study: Students are tasked with solving a real world issue. Brainstorming/discussion: Students get into groups to have in-class discussion about a real-world issue and assign each other disciplinary roles. Decision making: Students independently research issue from perspective of disciplinary role; then collaboratively discuss, complete, and submit (as a group) a worksheet that involves creating an experiment or proposal and integrates disciplines to address the real-world issue. Quiz questions: Students are tasked with answering quiz questions related to active learning module. **SUMMATIVE** Writing assignment: Students are given an essay assignment that tasks them with solving a real-world problem unrelated to DD topic. Exam questions: Students are tasked with answering exam questions related to DD module.	Students were given the appropriate tools to research limitations and benefits of disciplines throughout the course and in activities and assessments. Students were provided with opportunities to examine how other disciplines are necessary to solve real-world issues through activities and assignments. Students connected the importance to science and society through activities and assessments.
Disciplinary Grounding	Read and understand primary literature: know key concepts and seminal facts from each discipline with more emphasis on one	Collect relevant information from each discipline to establish background knowledge Display expertise in at least one disciplines while displaying provisional knowledge in other disciplines	Have different disciplinary roles in their assigned group Collect relevant disciplinary knowledge related to their role		Activities and assessments required students to review primary literature. Students were taught skills throughout course to develop disciplinary expertise as well as provisional disciplinary knowledge of other disciplines to address activities and assignments.
Different Research Methods	Know how to design appropriate experiments to address a given problem or research question	Identify appropriate methods from each discipline to address the problem	Collaboratively discuss how each role and methods will address the issue		Activities and assignments required students to design an experiment(s) and/or propose ways to gather more data.
Advancement Through Integration	Understand how different disciplines are needed to adequately answer a question	Identify how each necessary discipline and associated research methods contribute to a greater understanding of the issue	Collaboratively mix the different disciplines and associated methods in a unique way that culminates in a novel solution		Activities and assignments could not be fully and successfully answered through one discipline.
Collaboration Across Disciplines	Engage in collaboration	Be able to have productive collaborations	Identify the necessary collaborators and find common ground to work toward a feasible solution		Activities and assignments required students to develop common ground between classmates. Students identified necessary collaborators/disciplinary expertise to solve the real-world issues.

CBE—Life Sciences Education • 18:es3, Summer 2019

Tripp, B., & Shortlidge, E. E. (2019).

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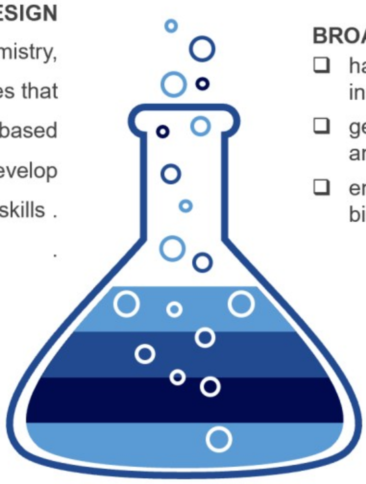
A transdisciplinary STEM lab

COURSE DESIGN

Integrate the disciplines of biology, chemistry, physics, and mathematics with activities that engage students in real-world, inquiry-based exercises and help students develop quantitative reasoning skills .



BROAD THEMES

- ❑ harnessing light's energy and investigating alternative energy sources,
- ❑ gel electrophoresis and molecular biology, and
- ❑ enzymatic reactions and the efficiency of biofuels.

ENGAGEMENT ACTIVITIES

- ❑Real-world, inquiry-based exercises
- ❑Develop quantitative reasoning skills

Slide 27

Case 2: B.S. in Transdisciplinary Studies in Engineering Technology (BS-TSET)

Students to complete a total of 120 credits of which about one-third are general education credits. The remaining two-thirds are split between core credits and free credits.

For the core credits, students are required to complete a Design-Studio course and ePortfolio course each semester.

For the free credits, students enrolled in the BS-TST major can select any courses from across the university, while the students enrolled in the BS-TSET major are limited to courses offered through the School of Engineering Technology.

In either case, the students are free to decide about one-third of the curriculum, which means they represent various pathways such as aviation management, industrial design, computer graphics technology, organizational leadership, and electrical engineering technology.

Themes including Play, Transportation, Renewable Energy, and Food, to name a few.

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Competency Clusters for Transdisciplinary and Competency-Based Education Program

Competency Cluster	Individual Competency
Create and Innovate	Systems Thinking
	Design Thinking
	Problem Scoping
	Entrepreneurial thinking
Interact with Others	Individual Contribution
	Give, Receive, and Act on Critique
	Leadership
	Emotional Intelligence
	Active Listening
Inquire and Analyze	Critical Thinking
	Quantitative Reasoning
	Qualitative Reasoning
	Information Literacy
Engage in Culture, Values, and the Arts	Cultural Engagement
	Arts Engagement
	Ethical Engagement
Communicate	Written Communication
	Oral Communication
	Visual Communication
	Integrated Communication

Ref: Bosman, L. & Duval- Couetil, N. (2019)

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Case 3- Transdisciplinary Education in Architecture and Engineering

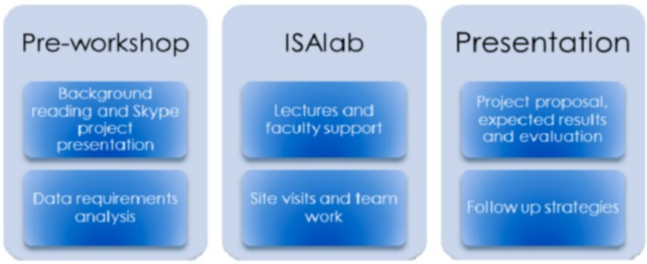

Figure 1. Workshop team interactions.

Indicators of Transdisciplinarity Skills

systems thinking, empathy, and metacognition

Ref: Orozcco- Messana, J et al. (2020)

Systems thinking is a core competency of sustainability knowledge involving the ability to connect the practical to the theoretical, and one level of a problem with multiple levels of the same problem

Empathic perspective-taking is relevant to engineers because it leads to understanding and care for the concerns and needs of stakeholders

metacognition is well-known to play an important role in high-quality learning by students and influences transdisciplinary interactions by enabling individuals to monitor, reflect on, and adapt learning processes in a multidimensional context.

Slide 30

Interdisciplinary assessment

- ❑ Instructors could develop quiz and/or exam questions related to the activity to assess whether students are making connections across disciplines and understanding related content.
- ❑ This could be followed by an individual writing-intensive assignment (e.g., essay, proposal, research paper)

Slide 31

Nature of Disciplines \ Learning Objectives	Knowledge (K)	Skill (S)	Practice (P)	Affective Domain (A)
Transdisciplinary (TD)	TDK	TDS	TDP	TDA
Interdisciplinary (ID)	IDK	IDS	IDP	IDA
Monodisciplinary (MD)	MDK	MDS	MDP	MDA

Fig. 2 Coding framework

Ref: Goa et al. (2020)

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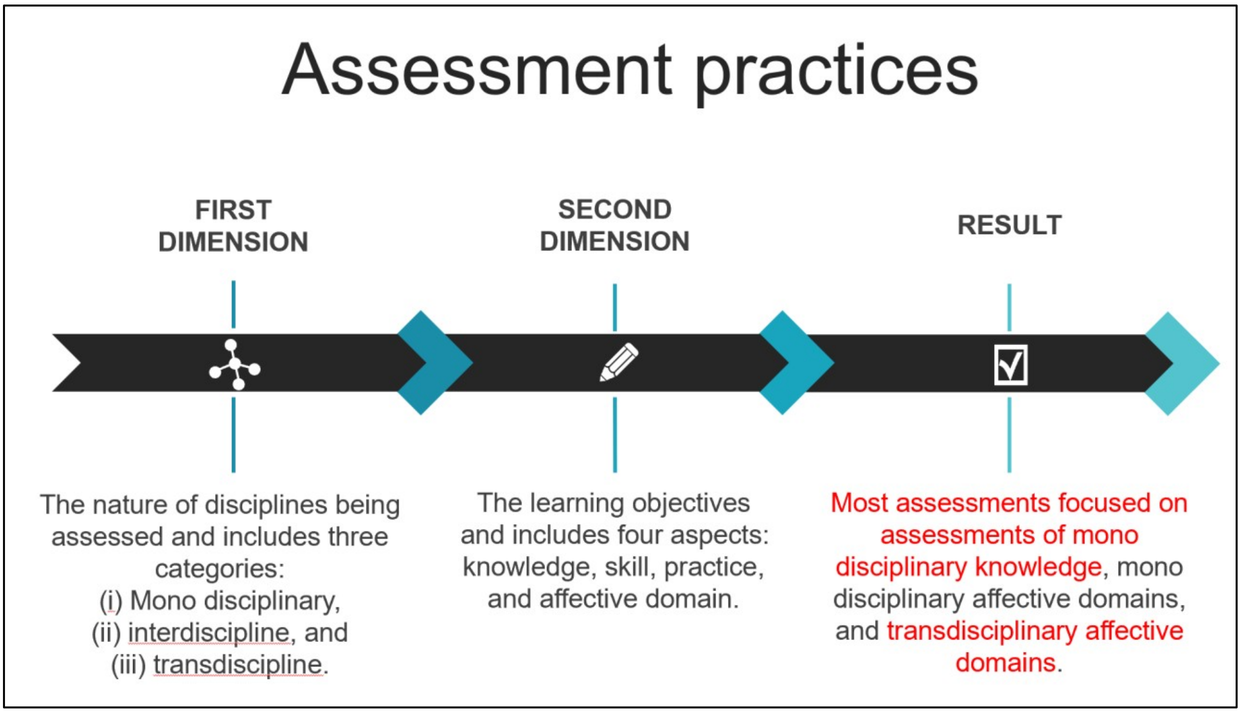

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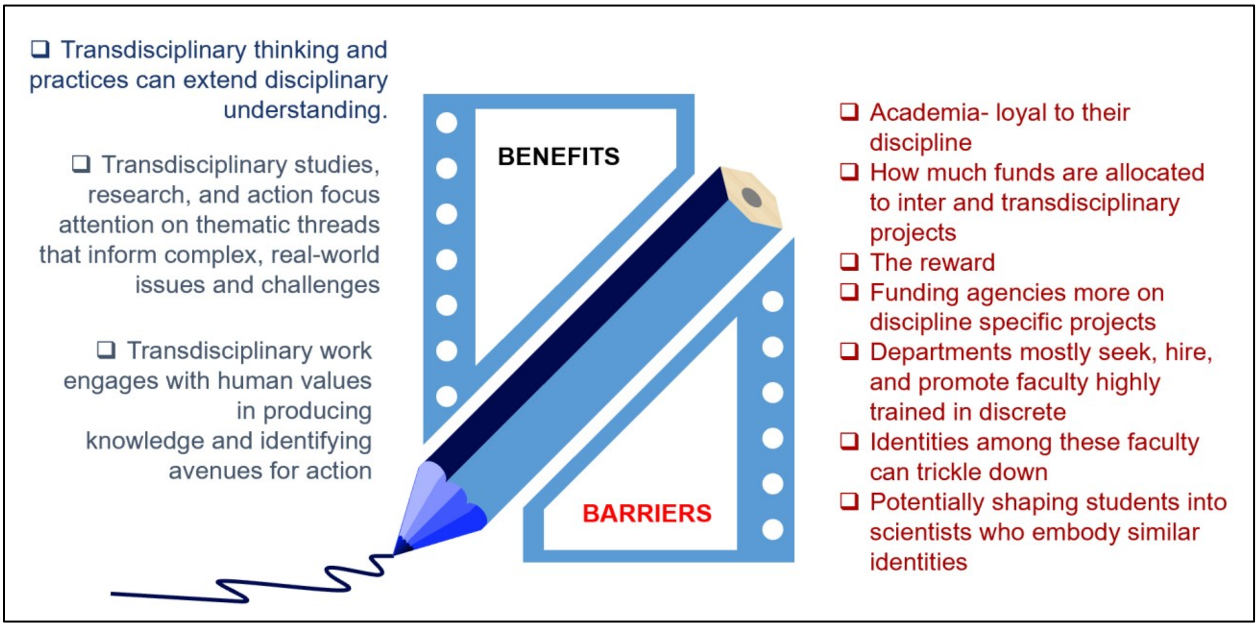

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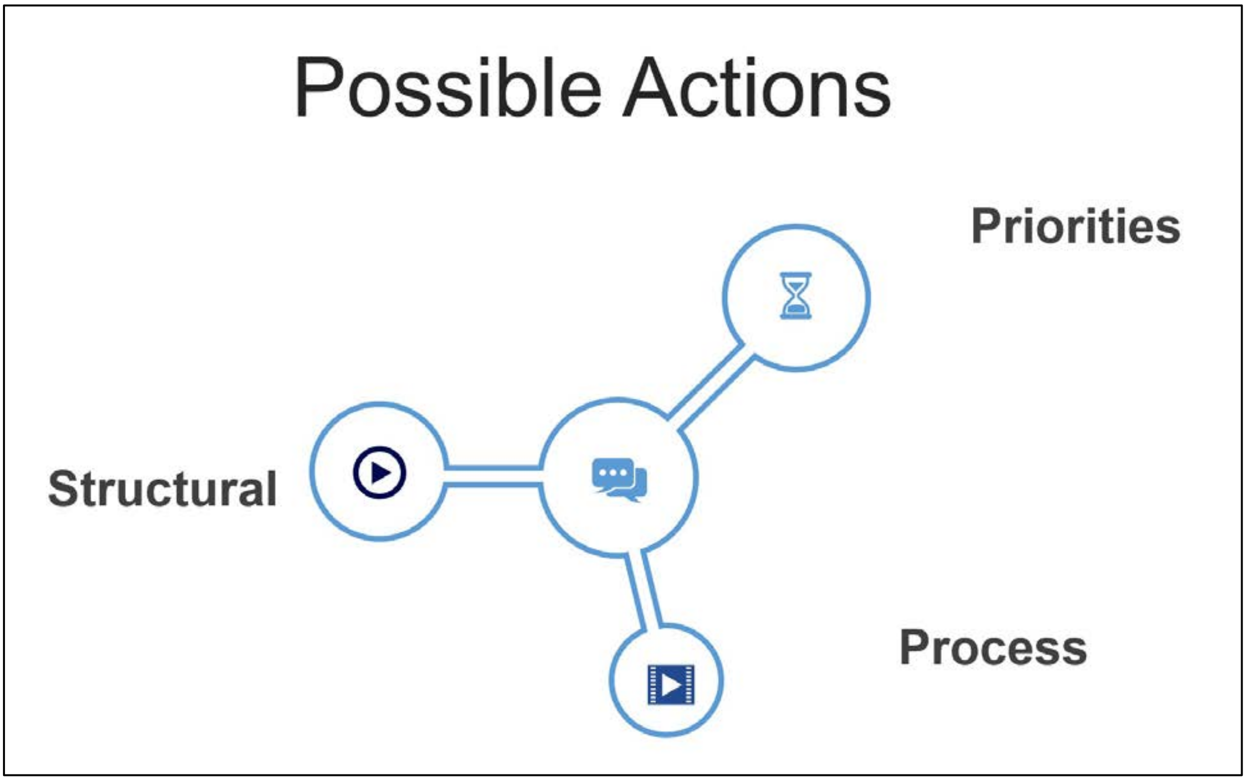

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Priorities

Country/ Region	Institution	Approach
United States	Arizona State University prototype for a 'new American university'	Redesigned the entire university using eight design aspirations: created multiple research centers, institutions, merged departments, created new academic units; view the research centers and institutes as the interface between the academy, industry and civil society; the transdisciplinary work happens at the interface (in the research centers and institutes) - called *working at the seams* (permeable boundaries); faculty are cross appointed between one or more departments and one or more research centers
Europe	- special meeting in Berlin about changing structures of the 21st century university in Europe (included reps from ASU)	Curriculum policy needs to support university frontiers of research that attends to complex societal issues; requires inter-sector conversations among emergent relationships
	- general comments about higher education in Germany	The federal and state governments' Excellence Initiative (*Exzellenzinitiative*) funds transdisciplinary science and research. It is divided along three funding lines: research. It is divided along three funding lines: (a) "future concepts" (development of the entire University), (b) "Clusters of Excellence" (promoting research around a complex subject), and (c) "Graduate School" (promotion of students in limited subject areas).
	- European Research Council (ERC)	the ERC established a first-ever research funding institutionthat completely transcends national borders; its mission to fund excellent research at the frontiers of knowledge, especially transdisciplinary

Mexico	Universidad Arkos University Center (Arkos)	Built a theoretical model of what a transdisciplinary (college/university would be like and, through planned in servicing (workshops, seminars and roundtables), convinced the university to implement it at the undergraduate level (all theses must be transdisciplinary); now aspiring for post-graduate programs

Australia	University of Technology, Sydney, the Institute for Sustainable Futures	Using behavior change theory, the institute, funded mainly by non-university grants and contracts (80%), contracts its services for transdisciplinary research projects. The university institute does not teach traditional university courses, and does not have undergraduate or even post graduate teaching degrees; it does have PhD and master level degrees. The students help the academics conduct the research.

Mcgregor, S. L. T., & Volckmann, R. (2011)

Slide 37

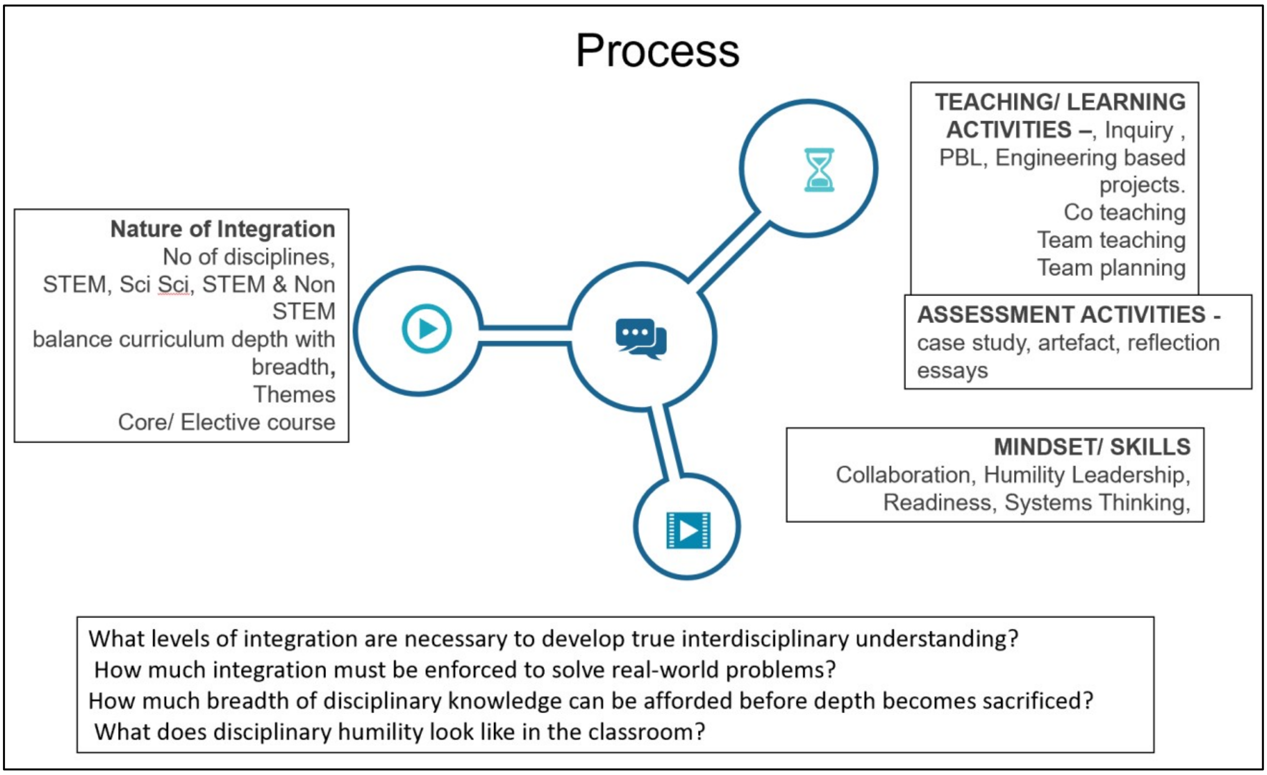
Structural

Faculty and administration to ensure success

Create interdisciplinary institutions

Create transdisciplinary research

Slide 38



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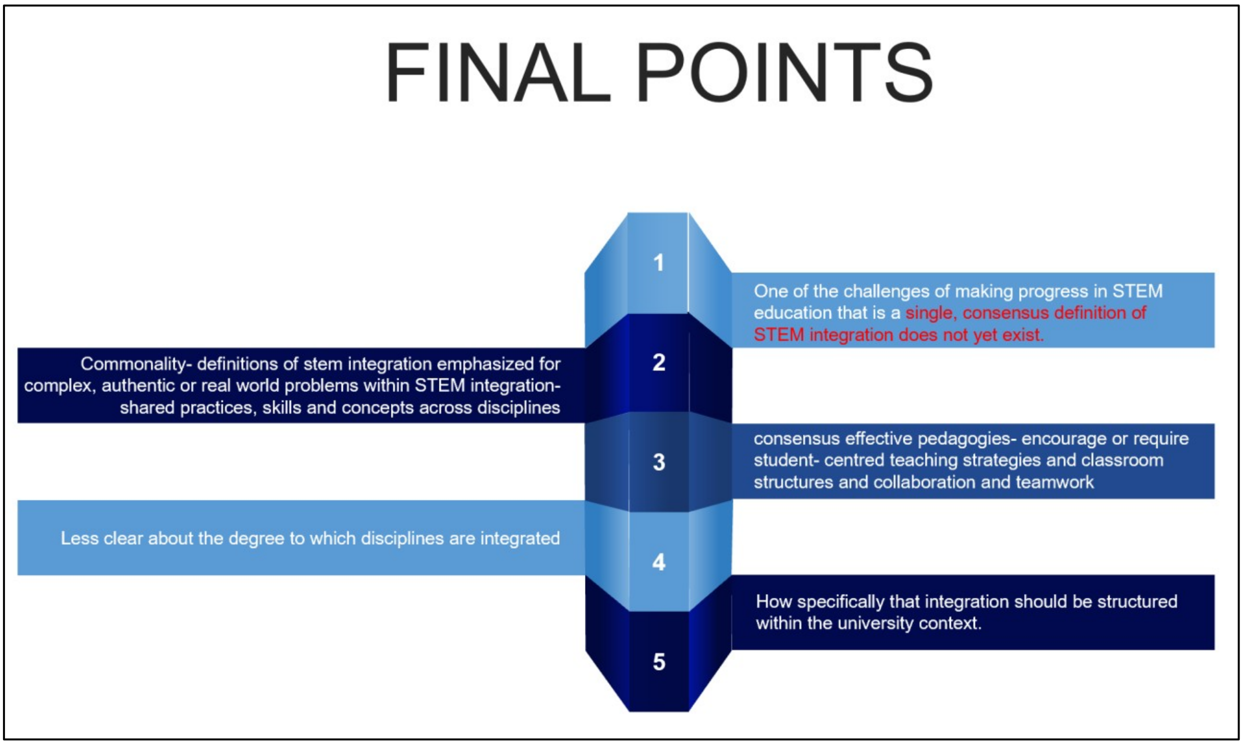
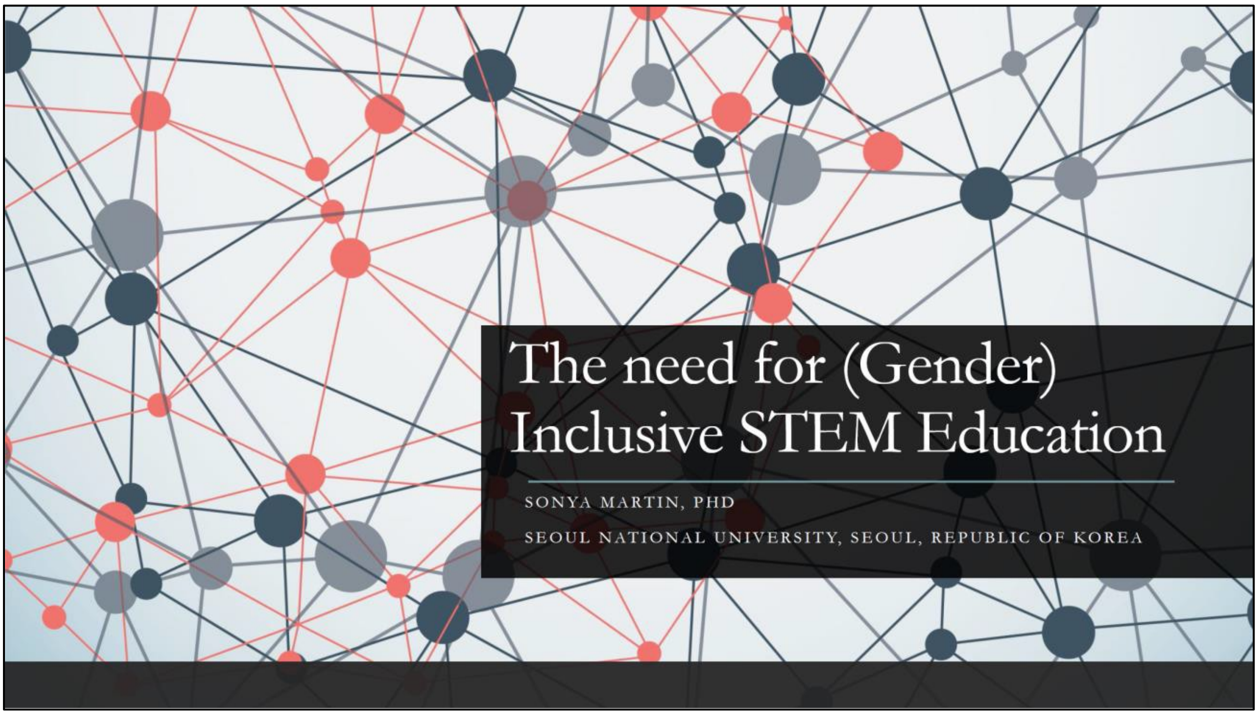


Slide 41

Slide 42

Appendix 7 – The Need for Gender-Inclusive STEM Education by Dr Sonya N. Martin



Slide 1

Overview

1. Why is gender equity an issue for STEM educators?
2. What is the STEM gender gap?
3. What has/is being done to address the STEM gender gap?
4. What is (Gender) Inclusive STEM?
5. What are barriers to (Gender) Inclusive STEM?
6. What are some benefits to (Gender) Inclusive STEM?
7. How can we overcome these barriers in STEM?

Slide 2

If diversity in STEM is important – why focus on gender issues?

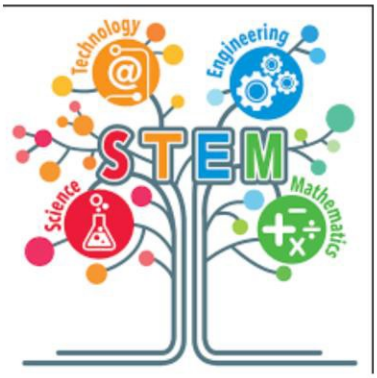
- Around the globe, STEM related occupations are expected to continue to grow in the coming decades – meaning countries need to produce more STEM educated people to fill these positions.
- If STEM initiatives are to be informed by diverse perspectives, we must ensure equitable access to STEM education and participation in STEM careers.
- Currently in most countries around the world - women, racial/ linguistic/ cultural minorities (within multi-cultural countries), socioeconomically disadvantaged people, and people with disabilities are under-represented in STEM education and careers.
- Systems that oppress individuals can intersect across multiple categories – such that poor, minoritized girls and women are often most excluded from STEM learning opportunities.

Slide 3

Why is under-representation of women/girls in STEM a problem?

Without equitable representation in STEM – Women/Girls have

- Fewer/reduced opportunities for economic advances available thru STEM careers **(economic concern)**
- Inadequate knowledge necessary to contribute to decision-making about important social issues **(social justice concern)**
- Decreased potential to contribute to fight in climate change and environmental issues **(environmental concern)**
- Fewer opportunities to share diverse perspectives that are needed in STEM **(diversity concern)**



Slide 4

Gender imbalance in STEM is not a new issue

While many studies from the last three decades show that all economies have reduced gender gaps in education and labor force participation, **gender differences in education and employment outcomes persist.**

Despite similar achievement scores among children of all genders in math and science, men represent an overwhelming majority of students studying STEM fields in higher education (OECD, 2019).

This is true even though world-wide as same numbers of girls and boys now complete secondary education and **more women graduate from university than men.**

Gender inequity is STEM education participation remains a persistent concern for educators, researchers, and government/policy makers.

Slide 5

What is the STEM gender gap?

The **labor gender gap is especially high in STEM fields** which **remains male-dominated** – but STEM occupations are expected to continue growing (Lund et al., 2019).

The few **women who begin careers in STEM face male-dominated** workplaces with **high rates of discrimination** (Funk & Parker, 2018).

Women in STEM report experiencing isolation caused by lack of access to women peers, role models, and mentors (Madgavkar, et al., 2019).

Women continue to be employed in lower paying occupations than men and continue to **earn less wages** than men in the same jobs (Funk & Parker, 2018).

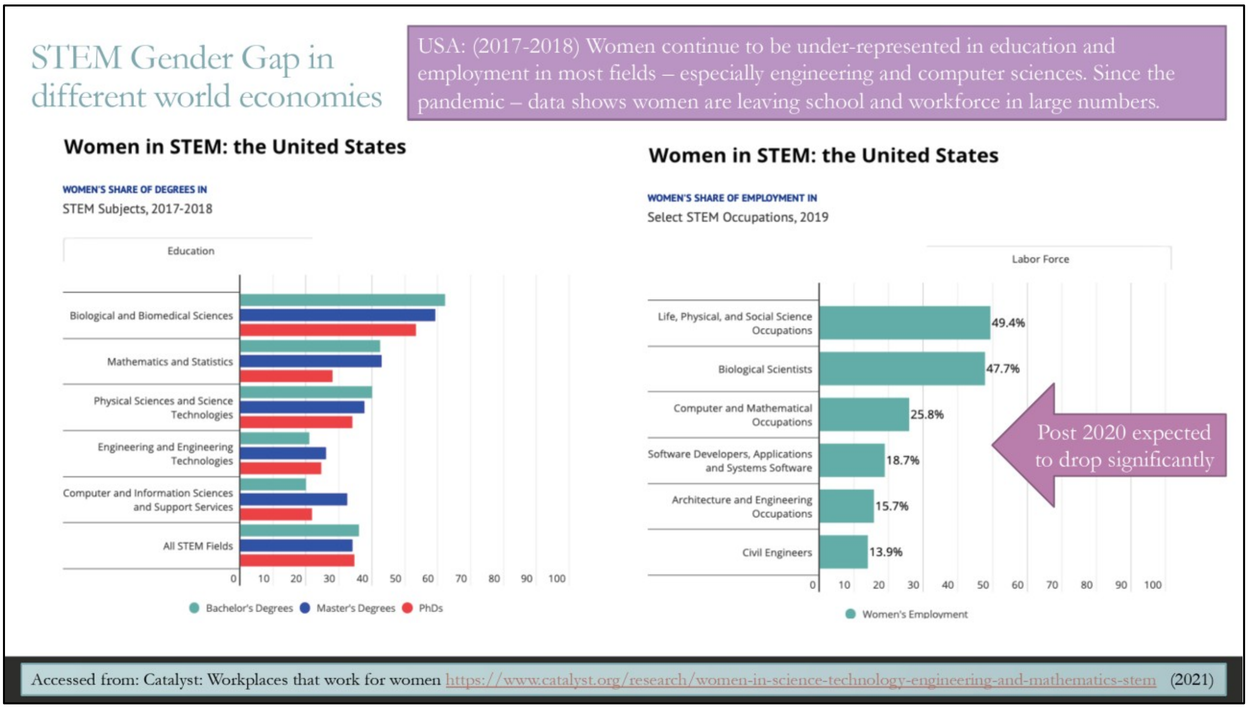
Women leave STEM careers at disproportionately higher rates than men. This is **particularly true for women in STEM who are also parents** (Frank, 2019; Else, 2019).

These factors contribute to an under-representation of women in STEM – leaving a "gender gap" between men and women in STEM education and careers.

Next few slides offer some "snapshots" of gender gaps in STEM in several economies.

Slide 6

Slide 7



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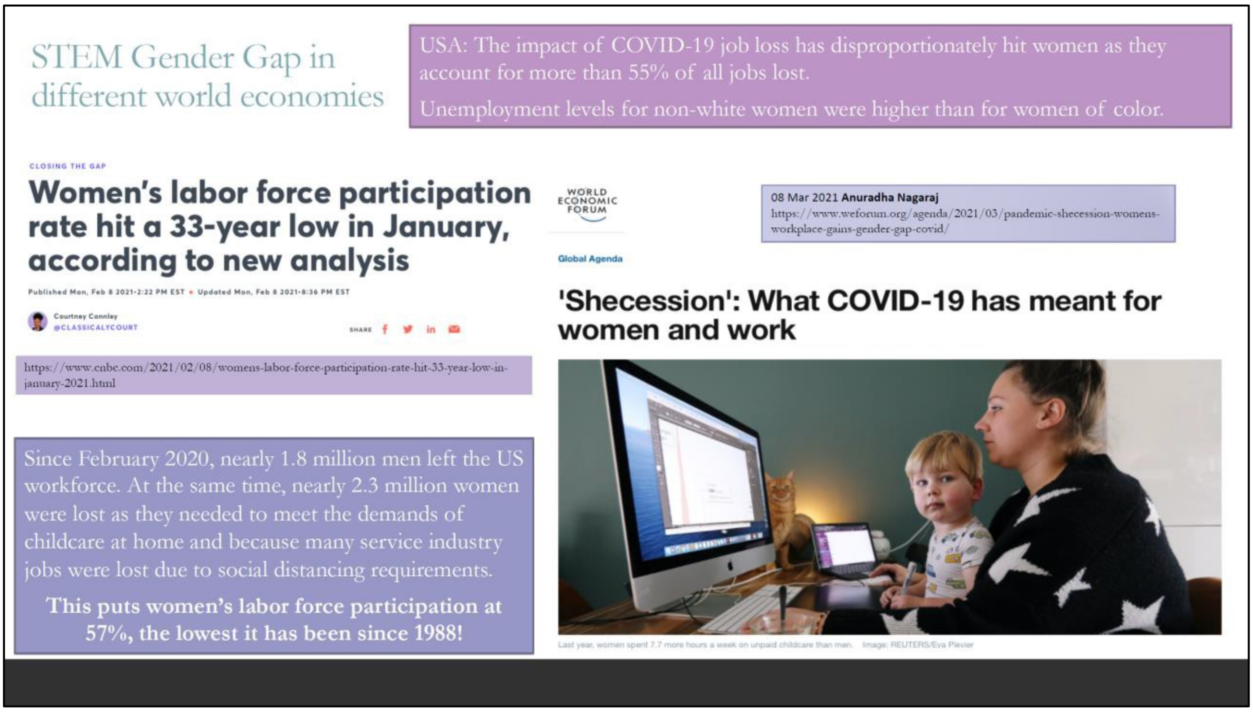

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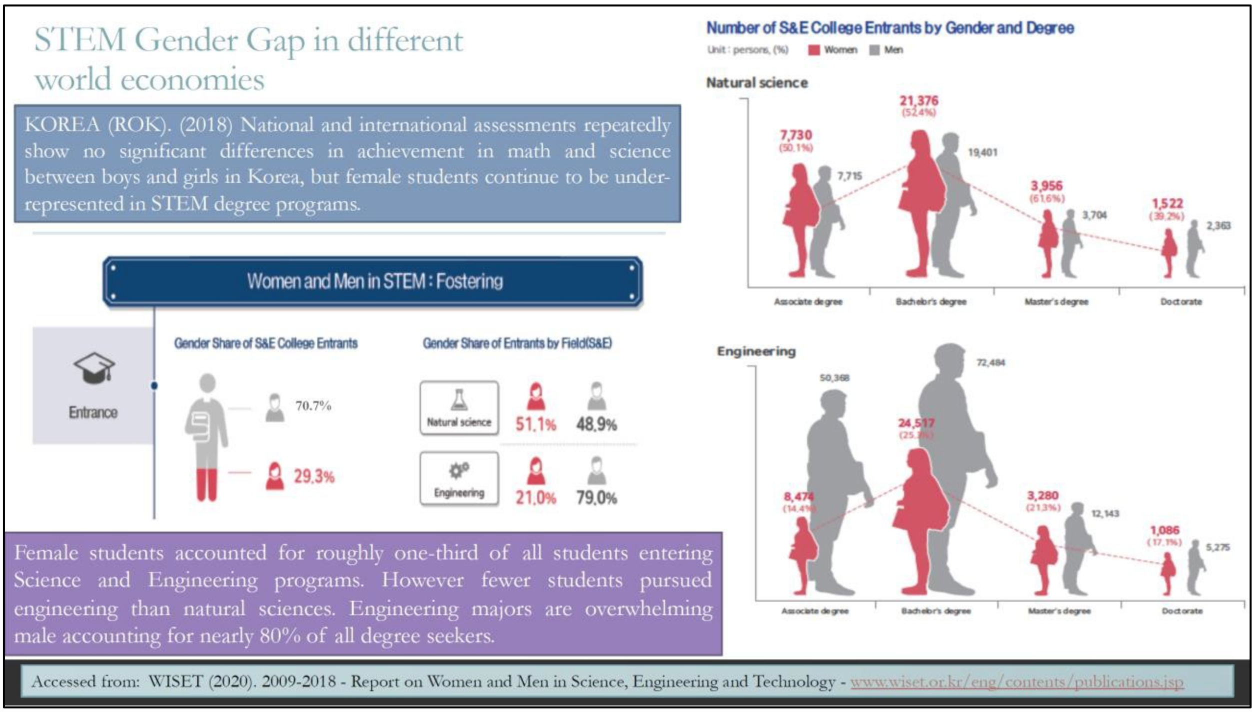
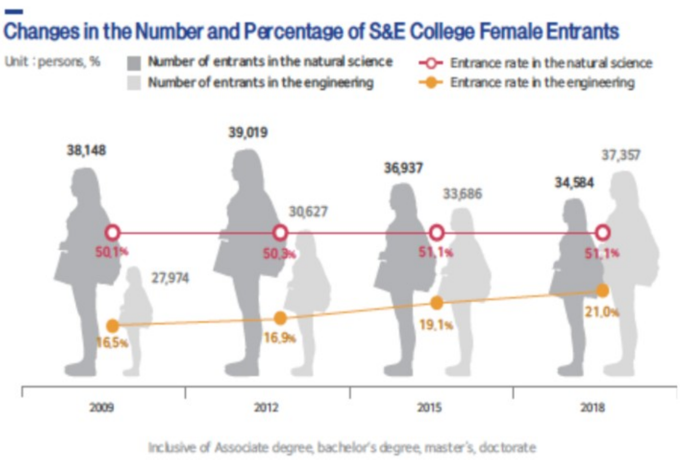


Slide 10

STEM Gender Gap in different world economies

KOREA (ROK). (2018) Even though the government has instituted a variety of educational policy initiatives since 2009, there has been little change in the number of female students entering Science and Engineering programs.

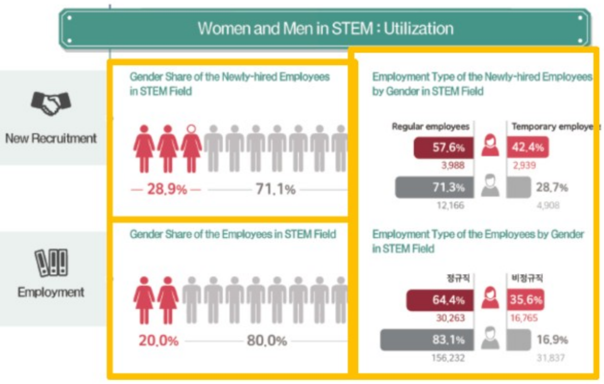


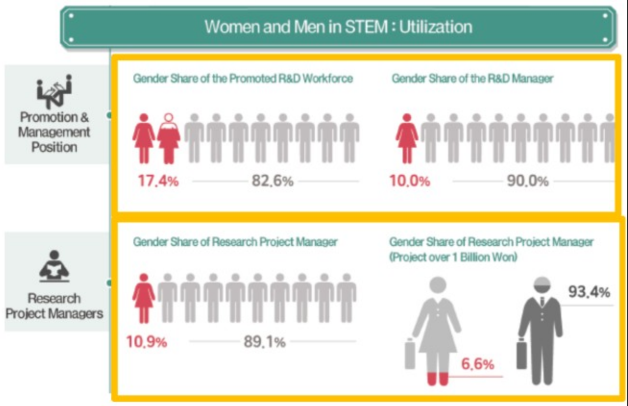
Accessed from: WISET (2020). 2009-2018 - Report on Women and Men in Science, Engineering and Technology - www.wiset.or.kr/eng/contents/publications.jsp

Slide 11

STEM Gender Gap in different world economies

KOREA. (ROK) (2018) There continues to be a lack of gender parity in both new recruitment and employment of women compared to men. In addition, women are more likely to be employed in temporary positions compared to men. Women are also less likely to be promoted or to serve in positions of power as managers for research projects.



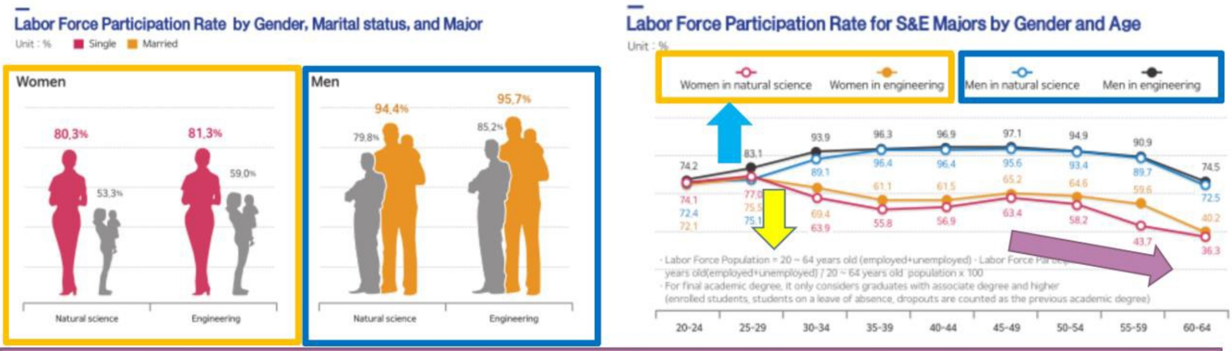


Accessed from: WISET (2020). 2009-2018 - Report on Women and Men in Science, Engineering and Technology - www.wiset.or.kr/eng/contents/publications.jsp

Slide 12

STEM Gender Gap in different world economies

KOREA. (ROK) (2018) Data show that married women in their 30s have a sharp drop in labor force participation compared to men of the same age. This gap has been attributed to career disruption for women due to child-care needs. Interestingly married men of the same age experienced an increased in the labor force for the same reasons.



As the number of veteran female scientists decreases, less diverse (gender) perspectives and experiences are brought to the development and doing of STEM research. In addition, the few women left report being excluded from informal networks which decreases opportunities for participating in the production of STEM knowledge.

Accessed from: WISET (2020). 2009-2018 - Report on Women and Men in Science, Engineering and Technology - www.wiset.or.kr/eng/contents/publications.jsp

Slide 13

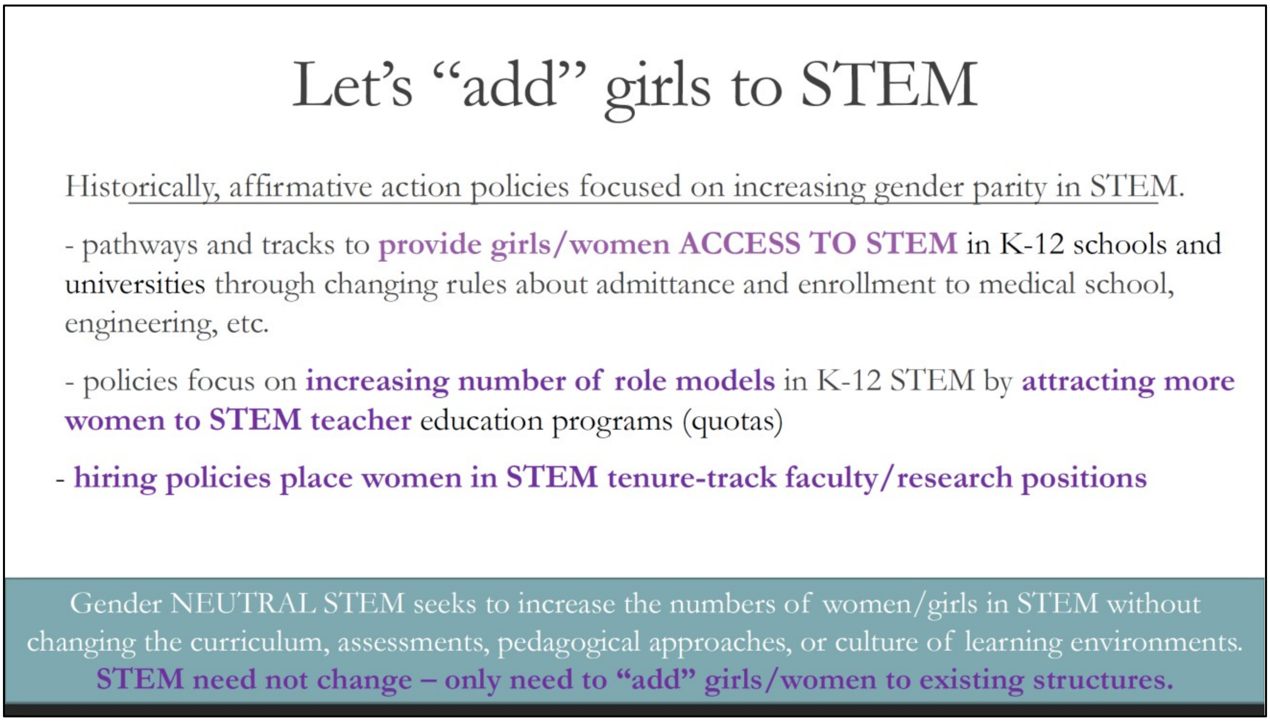
What is/has been done to address the STEM gender gap?

GENDER NEUTRAL STEM

Gender Equality Approach: this approach has informed major legislation around the world with focus on affirmative action programs (gender parity).

Assumption is that boys and girls are equal in their approaches to learning and interests in STEM – but obstacles (structures) existing "outside of STEM" account for girls' lack of participation.

Slide 14



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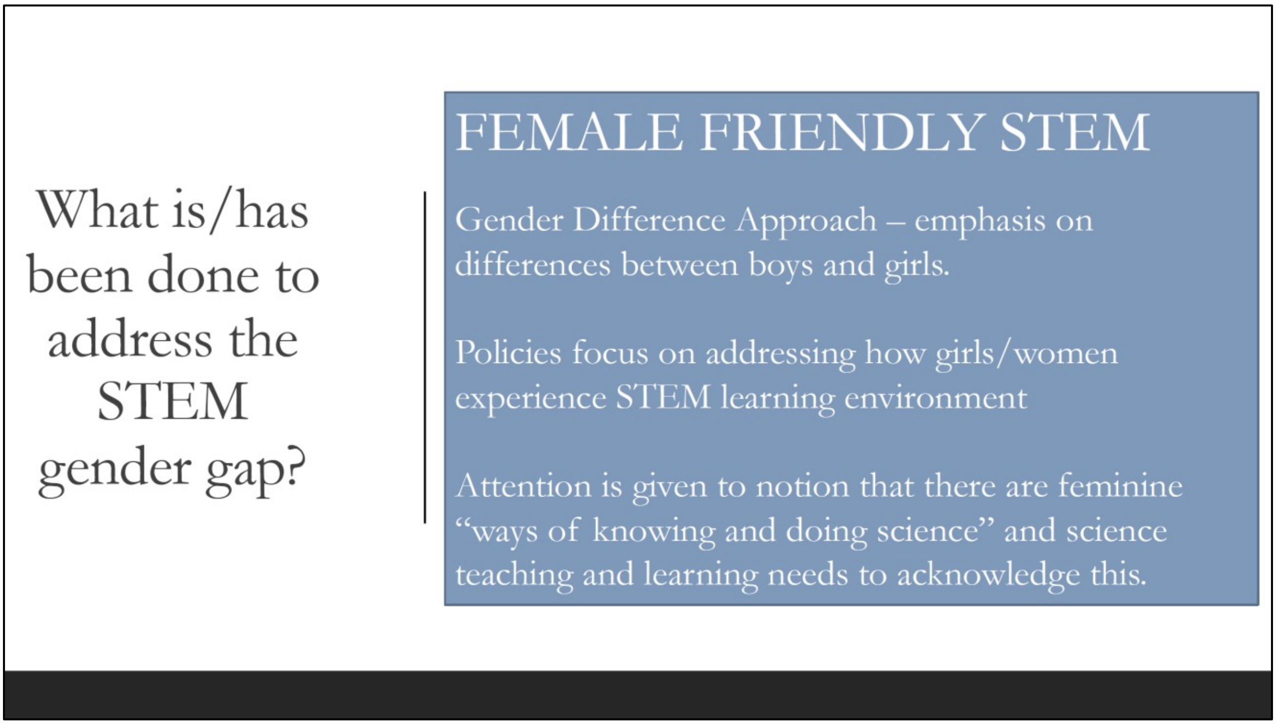

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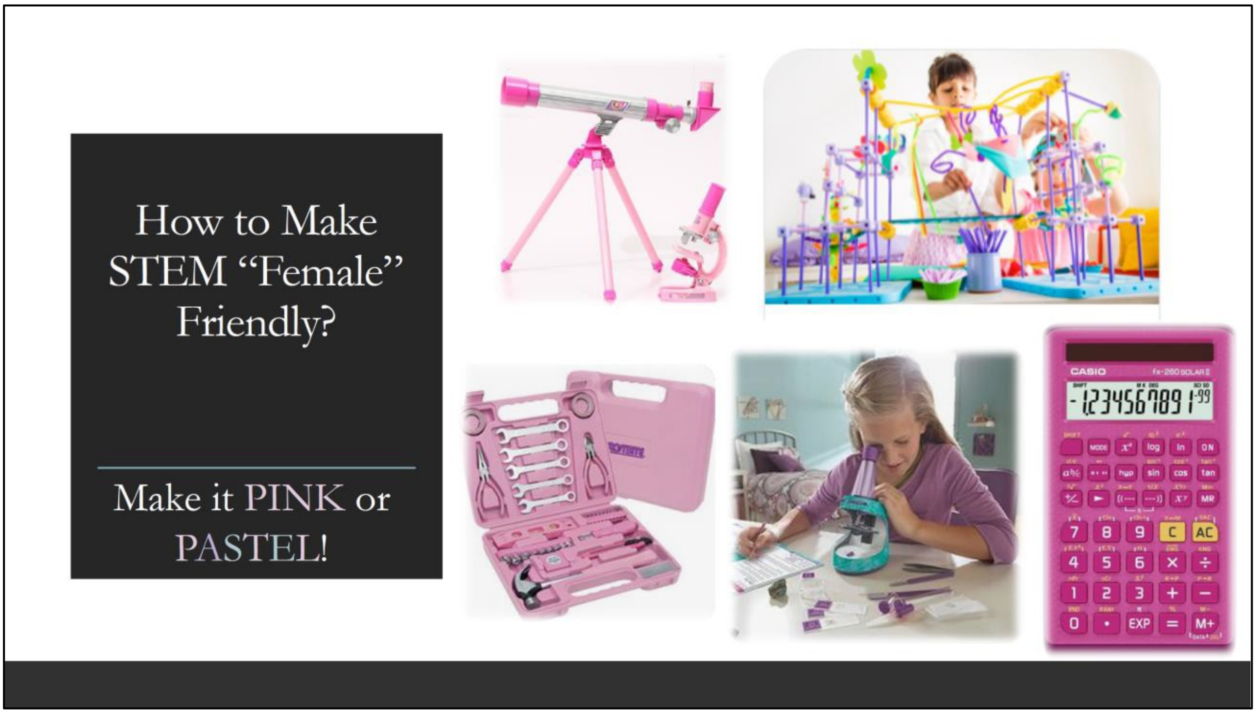

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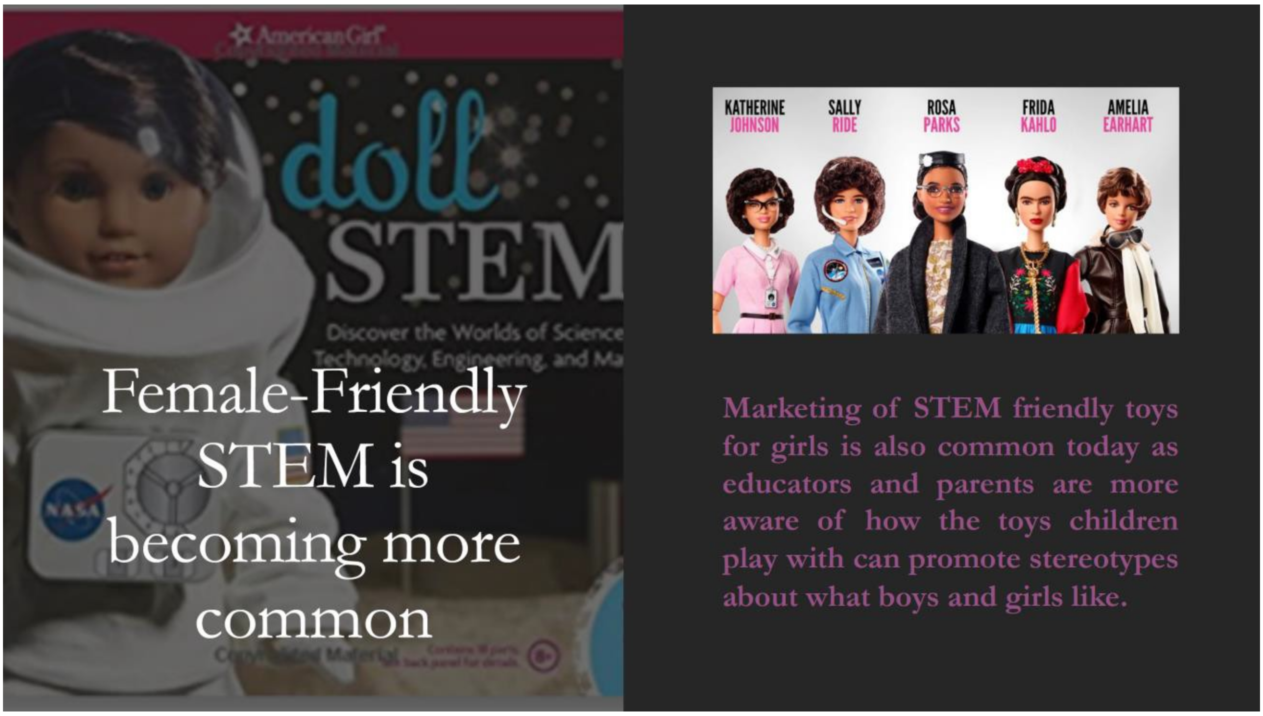

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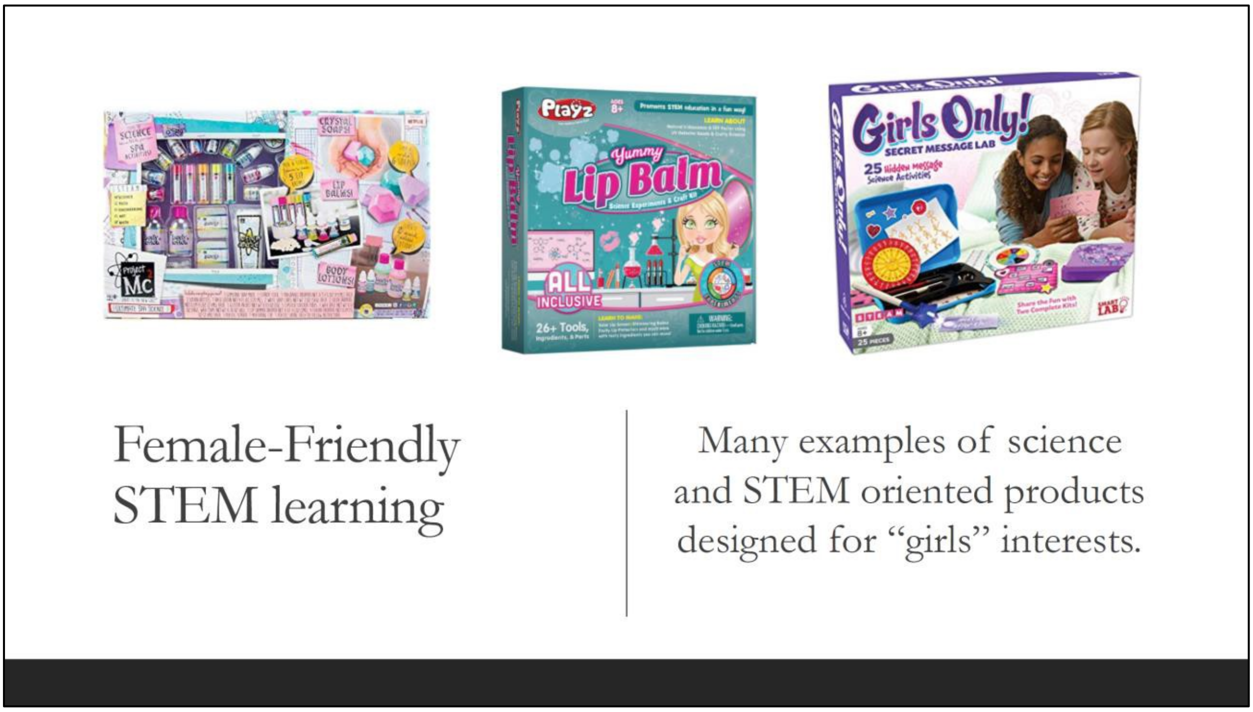


Slide 19

Slide 20

Female-Friendly STEM is very common

In schools, female-friendly STEM practices have placed emphasis on creating learning environments where the **(assumed)** interests, experiences, and abilities of girls/women are represented.

Female Friendly STEM romanticizes construction of females as "feminine" and does not acknowledge different ways of being female.

Slide 21

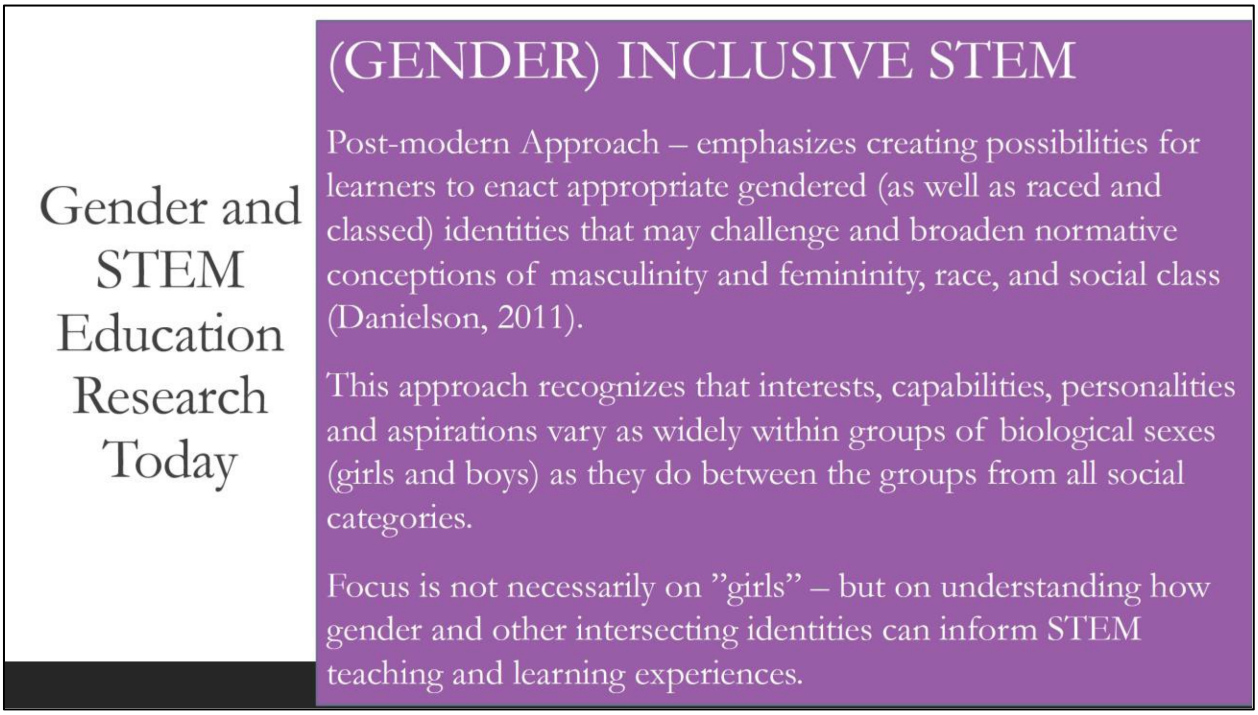
Gender and STEM Education Today

Assumptions that girls and boys belong to distinct, internally **homogeneous groups based on** their **biological sex creates 'stereotypes** about what it means to be girls and boys that fits no one in particular' (Brickhouse, Lowery, & Schultz, 2000, p. 442).

The assumption that sex equals gender is increasingly being challenged as **gender is increasingly being approached as a complex category** that individuals make themselves recognizable through and perform in various ways (Butler, 1993; Danielson, 2011).

Today many **researchers view gender as something individuals do (perform) rather than something they possess**. Thus, gender is increasingly being **studied as practices enacted** – not as fixed characteristics attributed to individuals based on sex (Achiam & Holmegaard, 2020).

Slide 22



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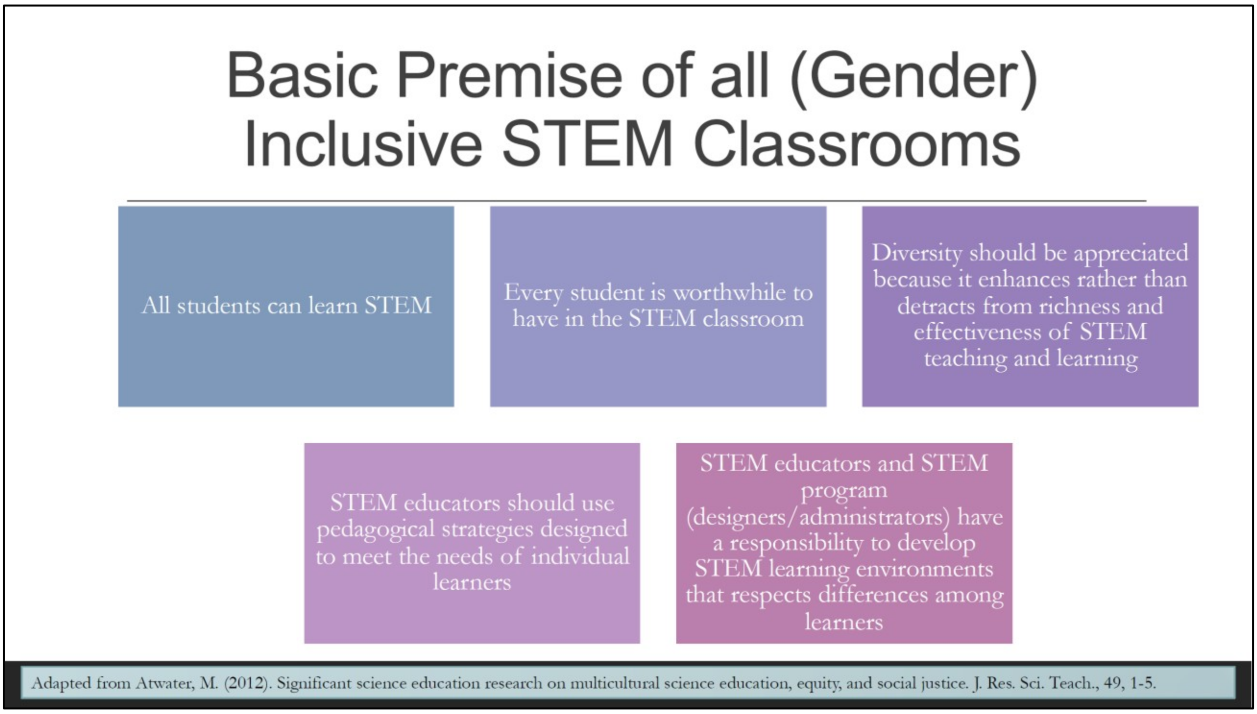

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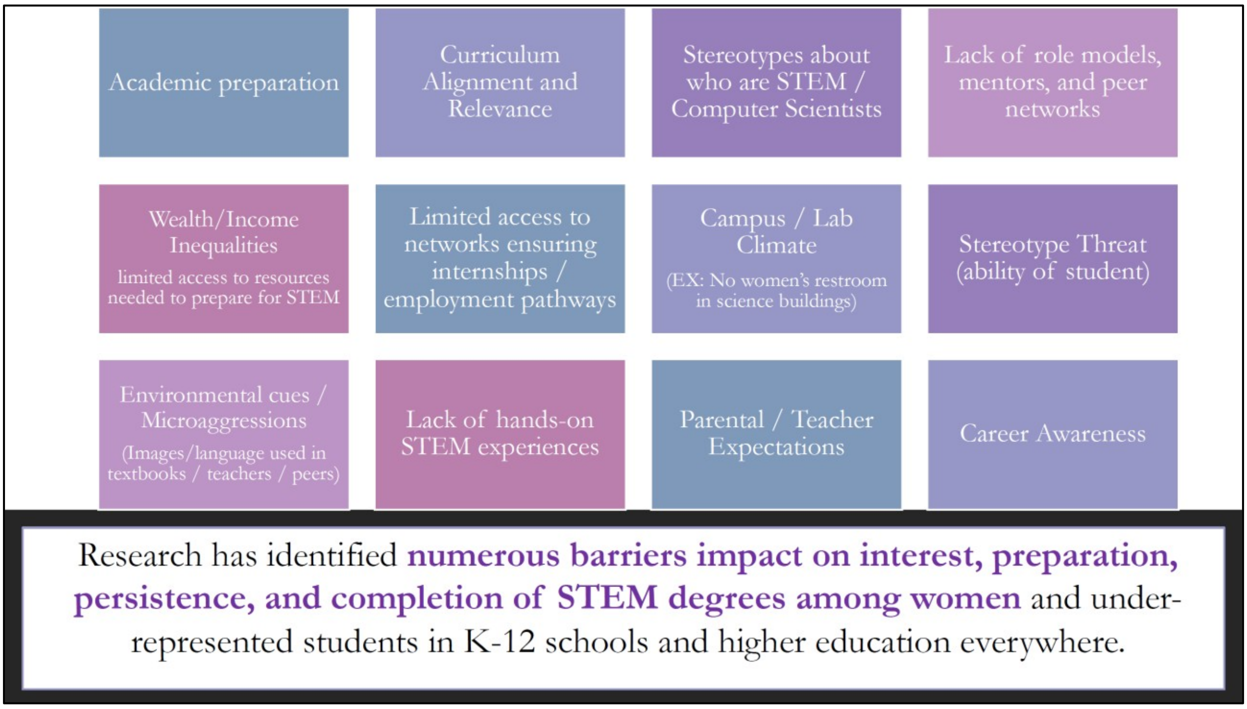

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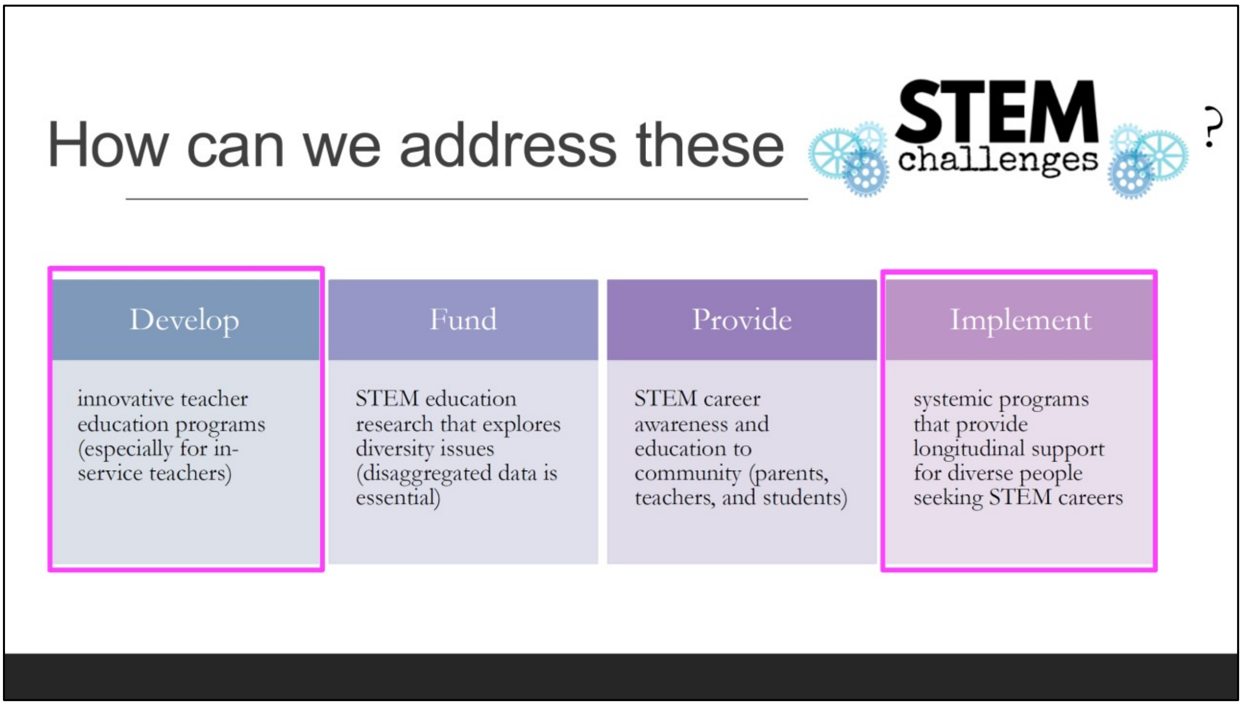


Slide 26

Criteria to Assess Gender Inclusiveness in Science Education Activities (Achiam & Holmegaard, 2020)

Individual Level	Interactional Level	Institutional Level	Societal / Cultural Level
What relevant prior knowledge do learners have?	Does the activity require different capabilities in a balanced way?	What is the institution's core aim and profile, and how does this set the scene for the activity?	How do public interest and ideas set the scene for the activity?
What scientific interests do the learners have?	What kind of interaction does the activity require?	How does the institution approach science, and how is this reflected in the institutional pedagogy?	What are the stakeholders' interests and how does that interact with the activity?
What previous experience do learners have with science?	What scientific role models do the learners encounter?	Does the institution focus on a specific scientific discipline, and is it represented in specific ways in the institution?	What are the cultural constraints for the activity?
What previous experience does the learner have with this type of institution?		What kind of engagement does the learning space support?	
How does the learner's sense of self or identity relate to the activity?			

Slide 27

Inclusive STEM Education Strategies offer powerful tools for teaching ALL students

These are all examples of instructional approaches that place students at the center.

Students are actively engaged in raising questions and working together to find ways to solve problems.

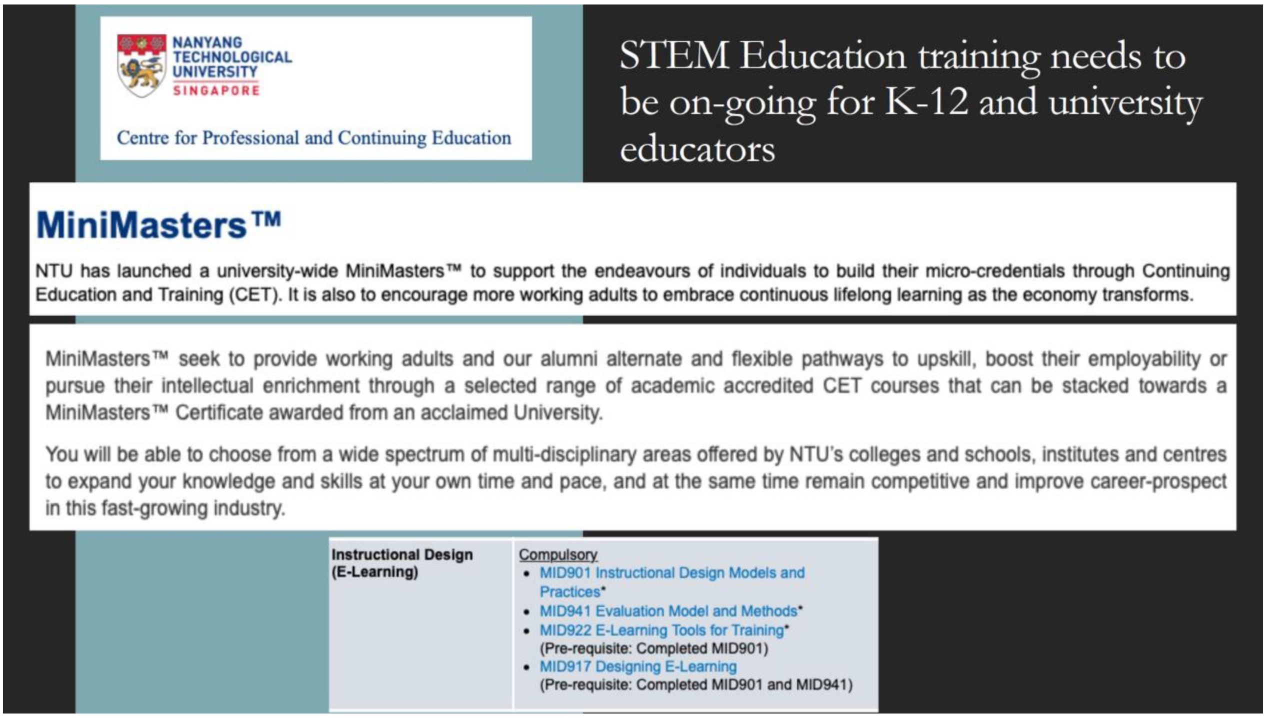
These strategies can be used to meet the learning needs and interests of ALL students (regardless of gender).

- Project-based learning
- STEAM Education
- Maker Education
- Collaborative Learning

But how can teachers stay updated on new research and instructional practices?

Slide 28

Slide 29



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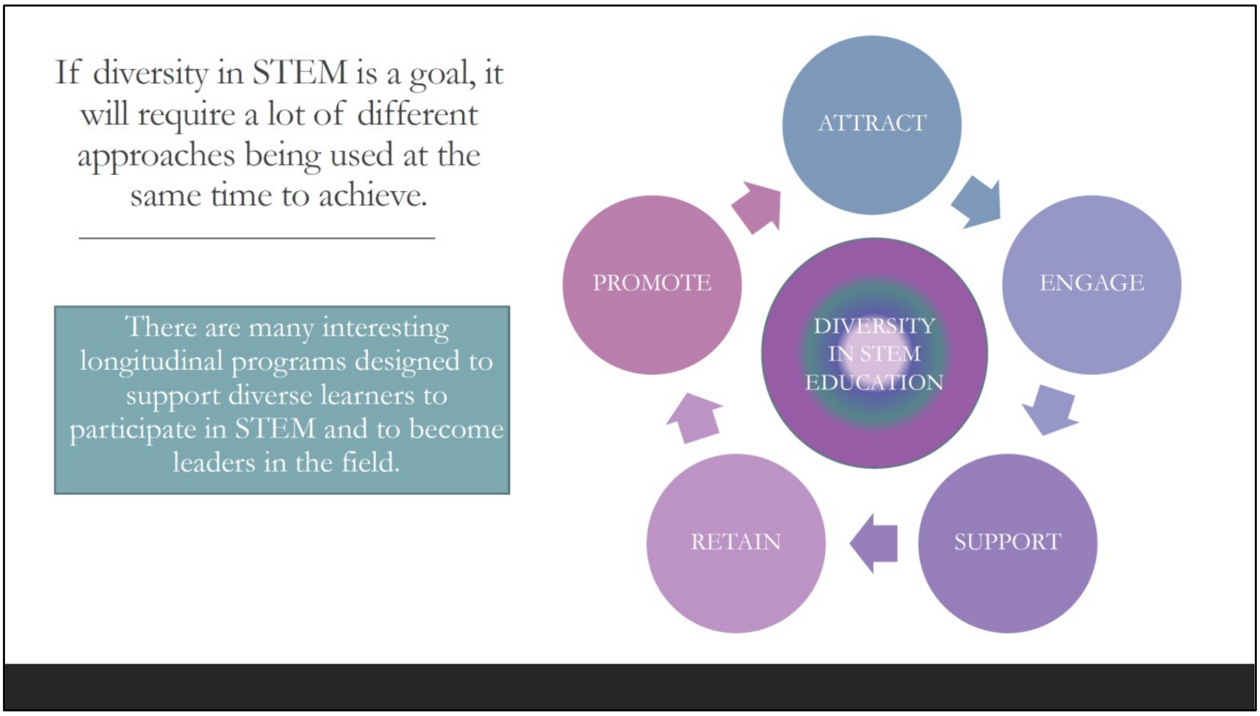

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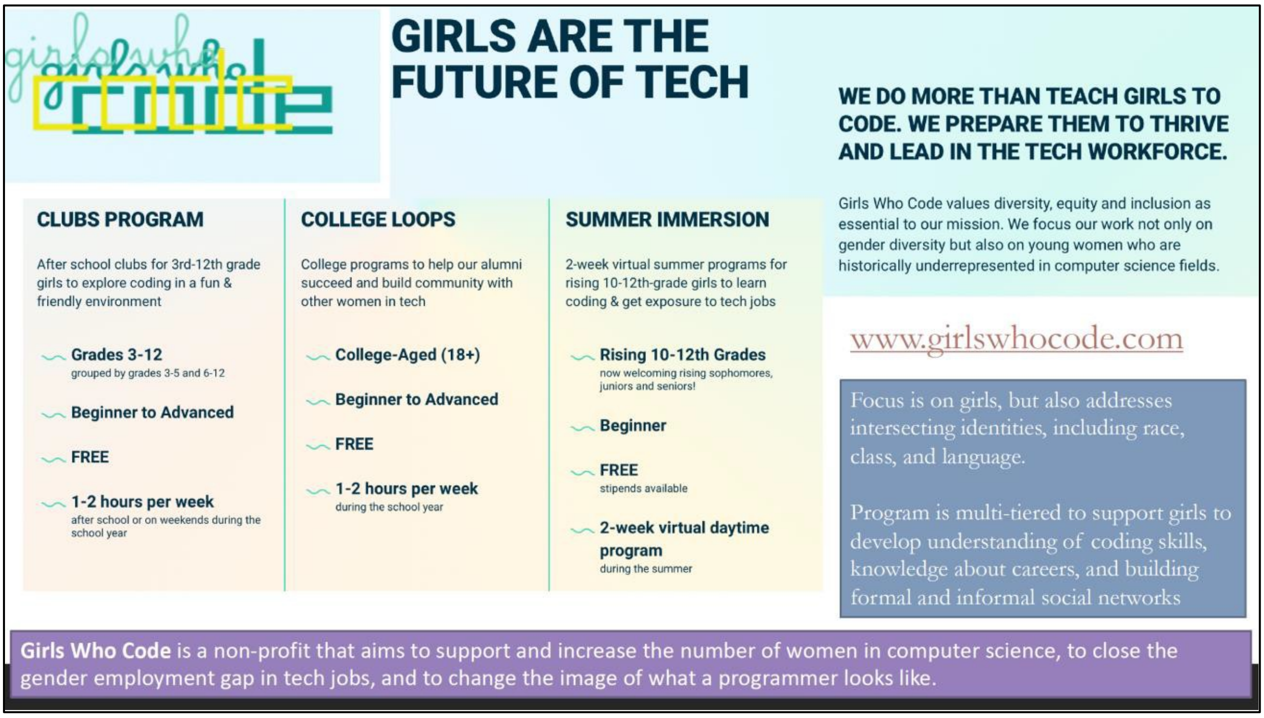

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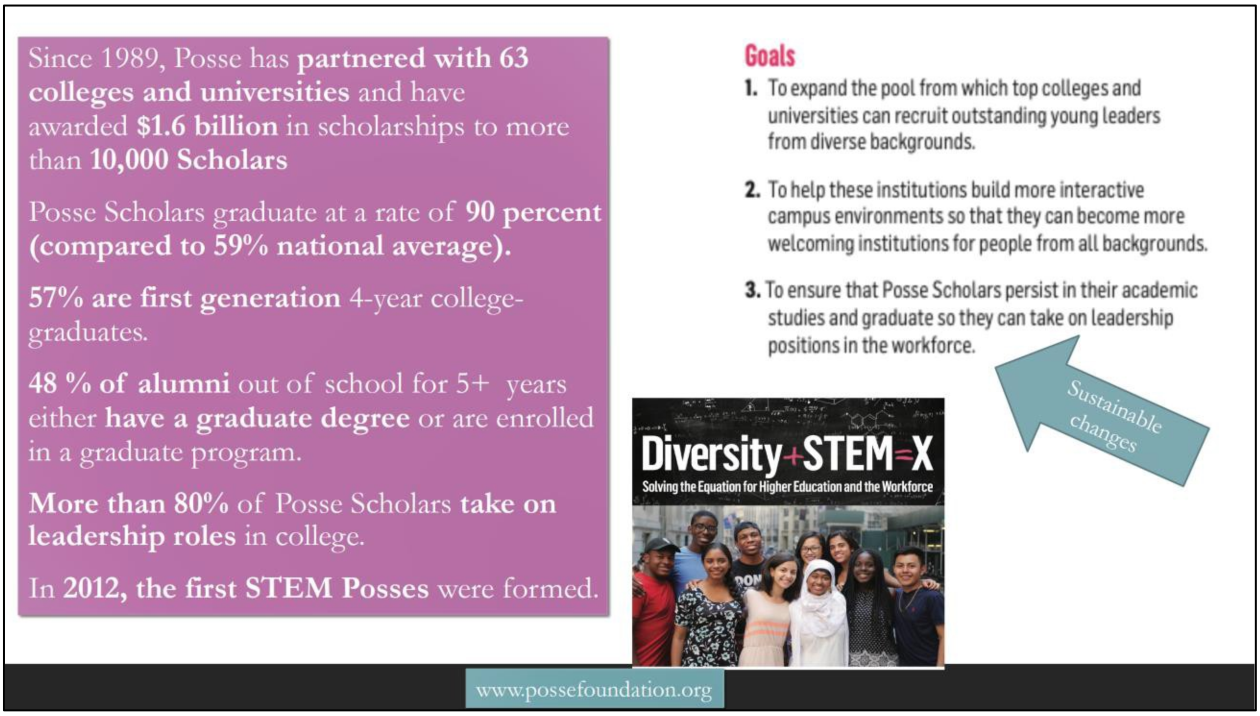

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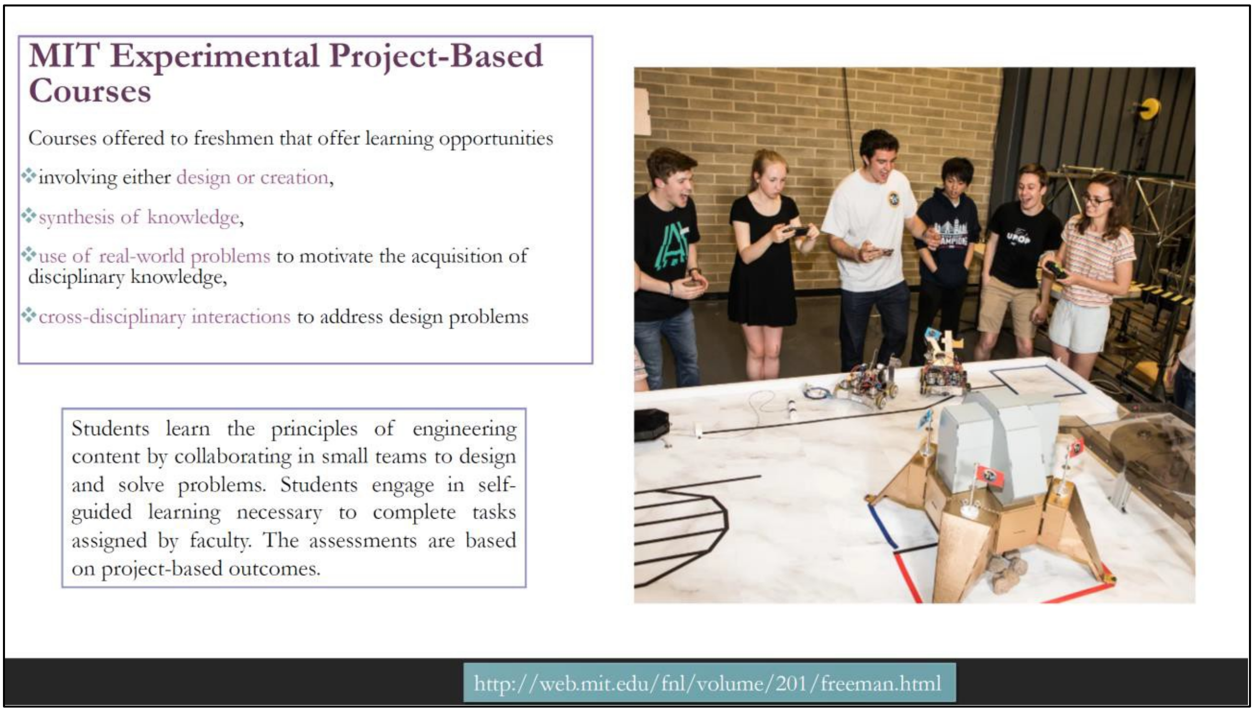


Slide 36

Slightly **more female students elect to enroll in these Project-Based Learning** courses (52%) compared to regular engineering courses (45%).

Females in PBL courses were significantly more likely than females non-PBL class to agree that:

- I have been able to talk to faculty outside of class about my interests.
- Some faculty now know me well enough to write a good letter of recommendation for me.
- Faculty have been encouraging and helpful.

MIT Experimental Project-Based Courses

Courses offered to freshmen that offer learning opportunities

- involving either design or creation,
- synthesis of knowledge,
- use of real-world problems to motivate the acquisition of disciplinary knowledge,
- cross-disciplinary interactions to address design problems

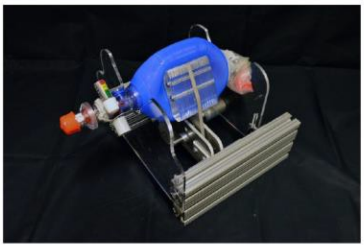
Confidence in teaming skills was significantly higher among PBL students than for non-PBL students - but the differences for PBL females were significantly higher than for non-PBL students.

PBL-females reported more confidence working with technology and significantly higher self-confidence in their ability to perform technology-oriented tasks than non-PBL females.

MIT-based team works on rapid deployment of open-source, low-cost ventilator

Clinical and design considerations will be published online; goal is to support rapid scale-up of device production to alleviate hospital shortages.

David L. Chandler | MIT News Office
March 26, 2020



http://web.mit.edu/fnl/volume/201/freeman.html

Slide 37

Criteria to Assess Gender Inclusiveness in Science Education Activities (Achiam & Holmegaard, 2020)

Individual Level	Interactional Level	Institutional Level	Societal / Cultural Level
What relevant prior knowledge do learners have?	Does the activity require different capabilities in a balanced way?	What is the institution's core aim and profile, and how does this set the scene for the activity?	How do public interest and ideas set the scene for the activity?
What scientific interests do the learners have?	What kind of interaction does the activity require?	How does the institution approach science, and how is this reflected in the institutional pedagogy?	What are the stakeholders' interests and how does that interact with the activity?
What previous experience do learners have with science?	What scientific role models do the learners encounter?	Does the institution focus on a specific scientific discipline, and is it represented in specific ways in the institution?	What are the cultural constraints for the activity?
What previous experience does the learner have with this type of institution?		What kind of engagement does the learning space support?	
How does the learner's sense of self or identity relate to the activity?			

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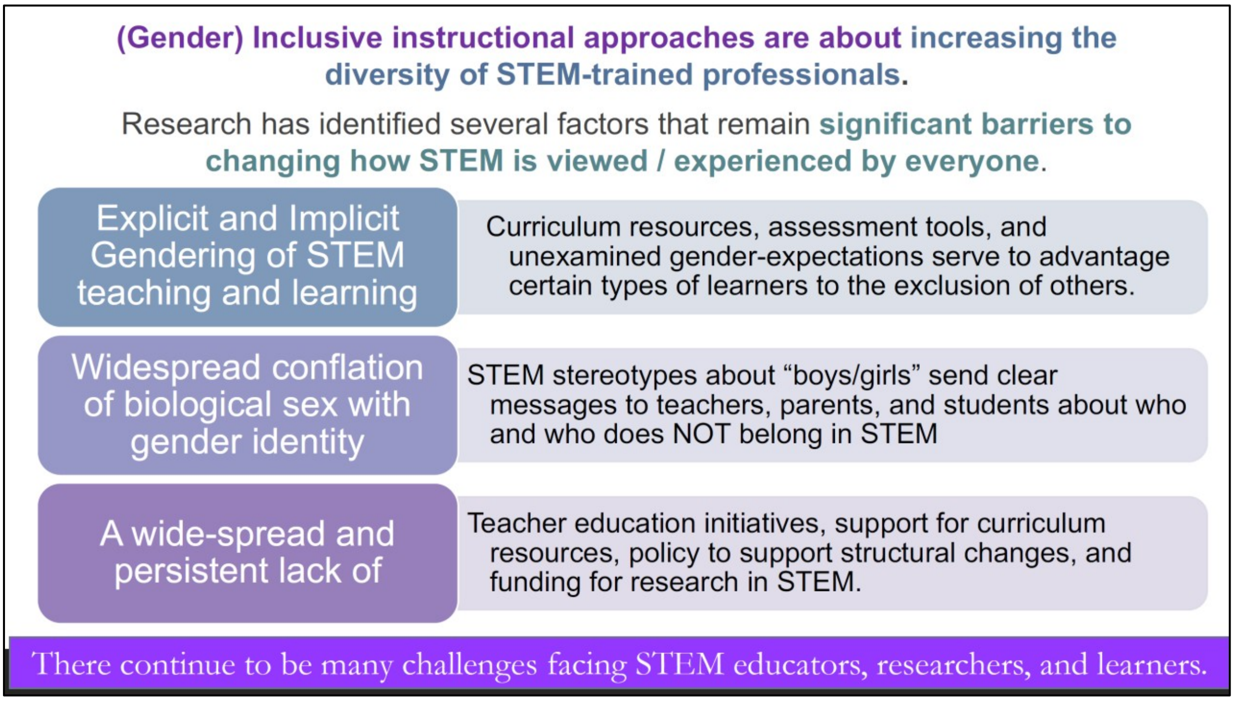

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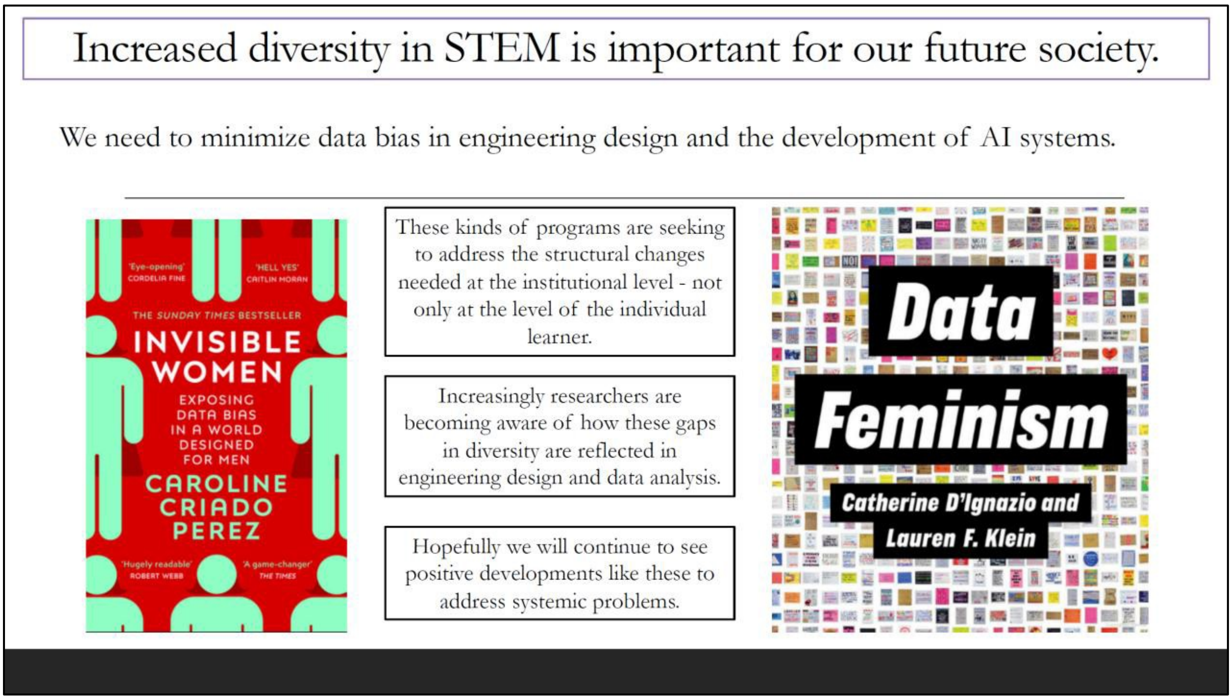

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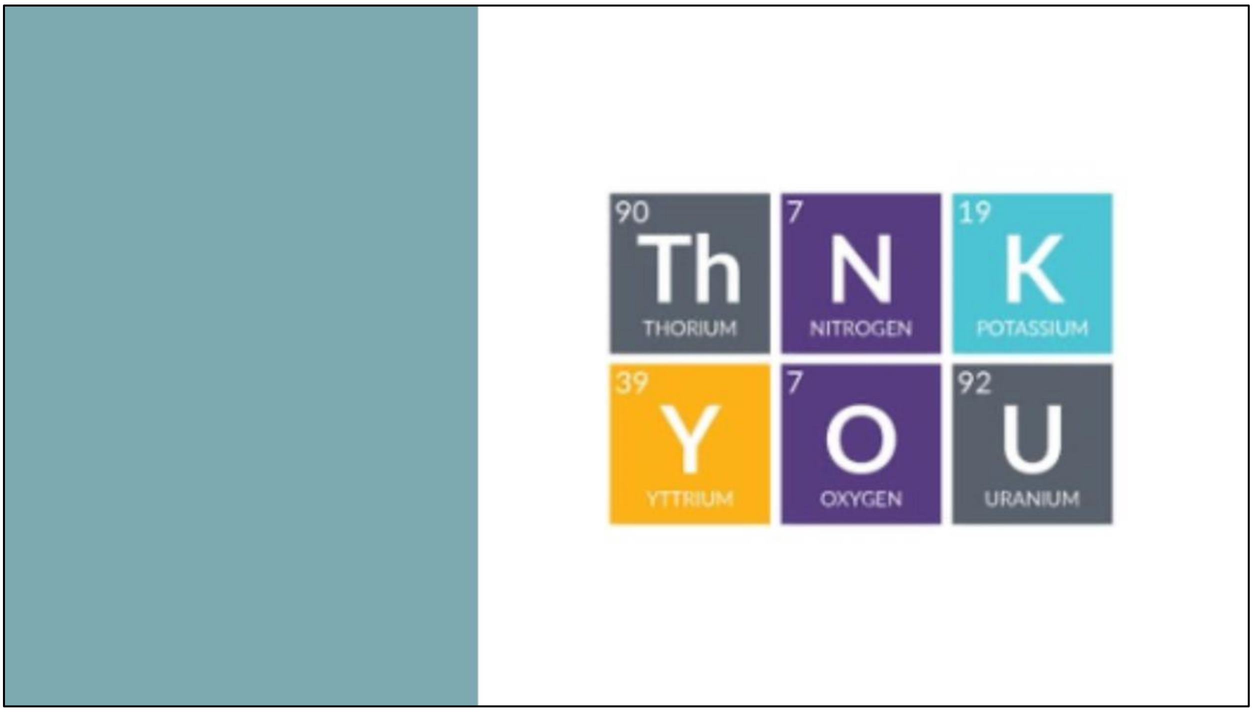

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Thank you card accessed at - https://www.catchmyparty.com/vendors/product/periodic-table-card-chemistry-science-theme

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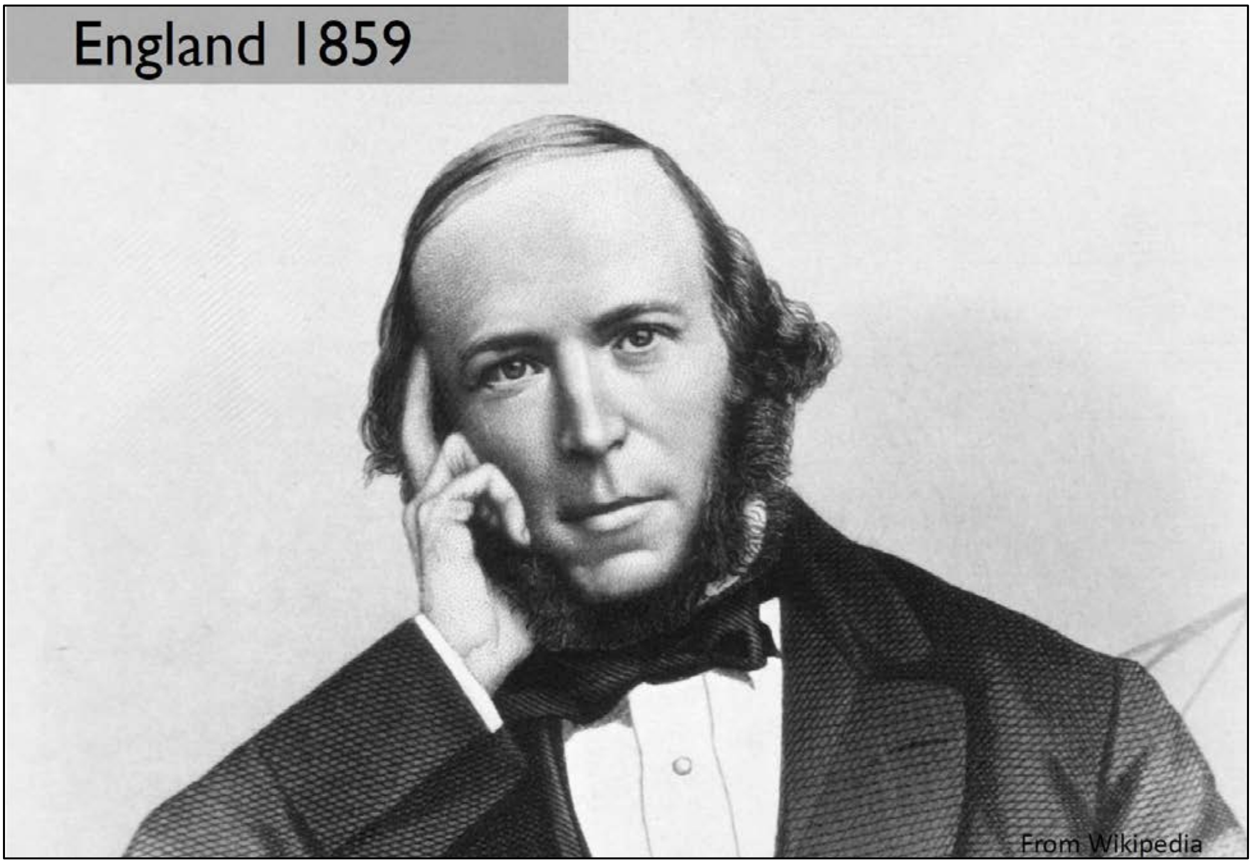
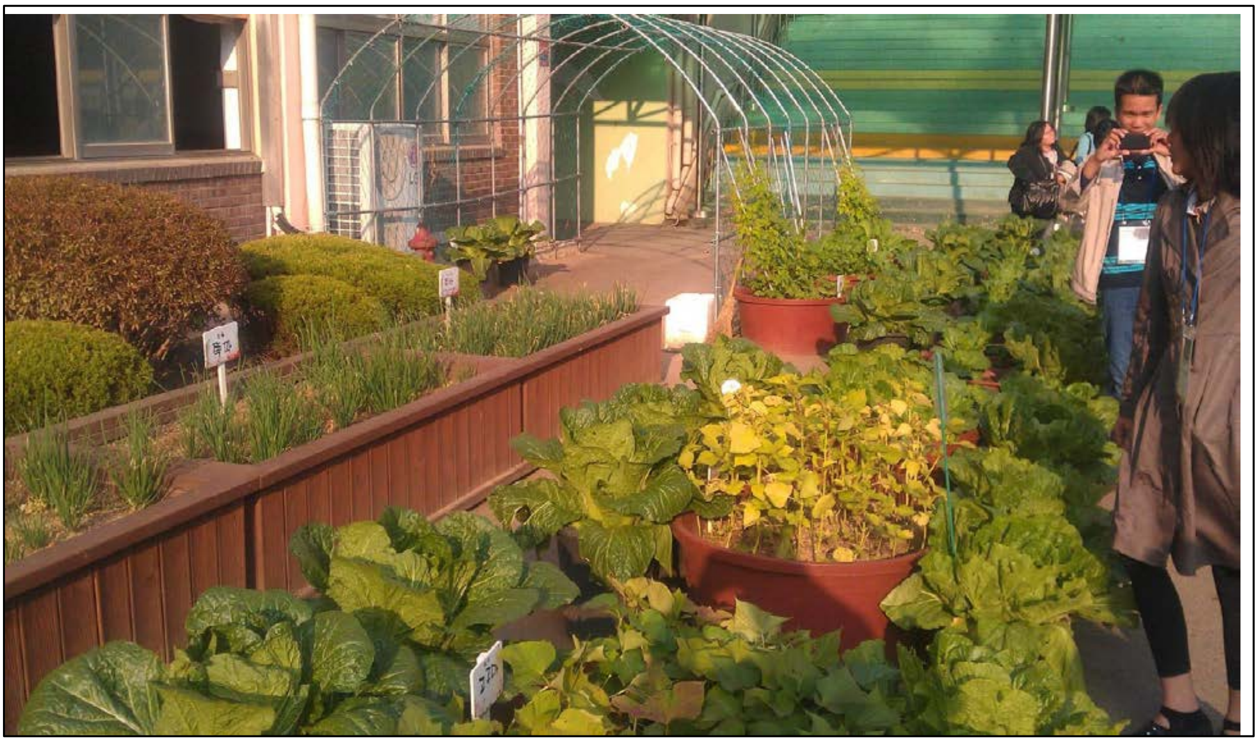
Appendix 8 – Curriculum Models for STEM by Dr Yew Jin Lee

Slide 1



Slide 2 (Source: https://en.wikipedia.org/wiki/Herbert_Spencer#/media/File:Herbert_Spencer_5.jpg)



Slide 3

Slide 4

What STEM knowledge & experiences are of most worth?

Spencer's question for us…

6

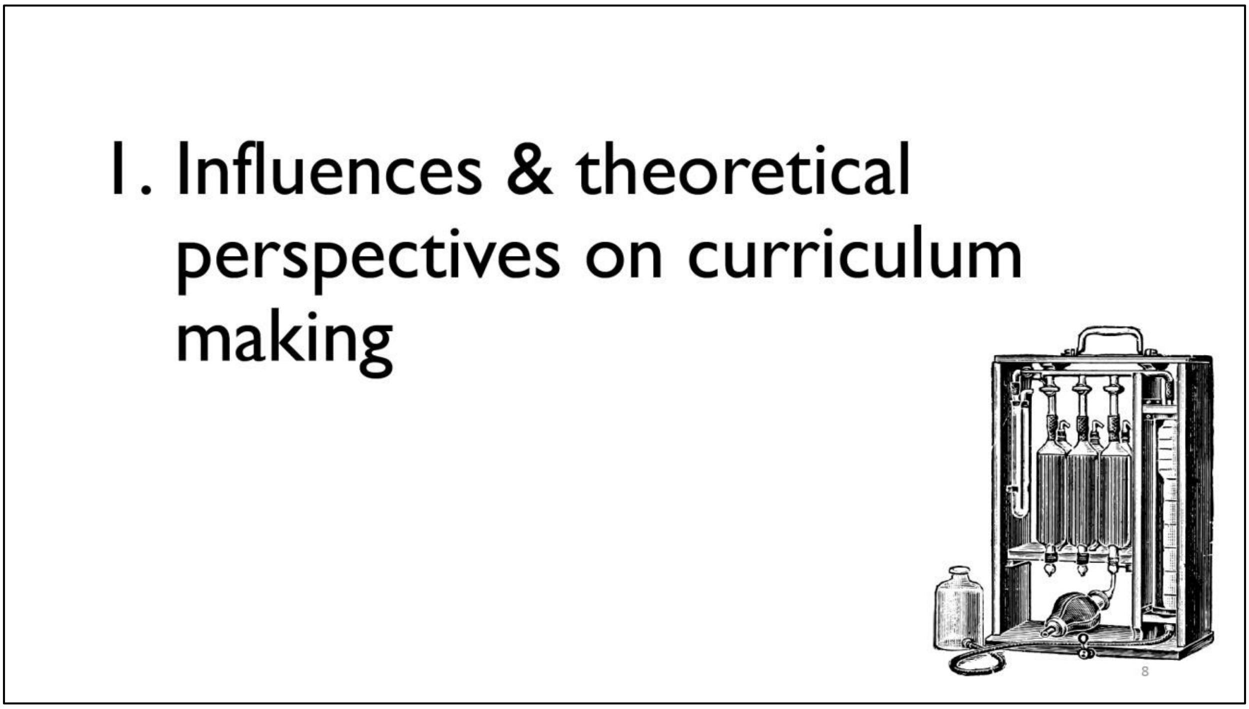
Slide 5

Purposes & structures of a STEM curriculum model

1. Influences & theoretical perspectives on curriculum making – where we are coming from
2. General organization of a curriculum
3. Organization of topics/courses for STEM

7

Slide 6



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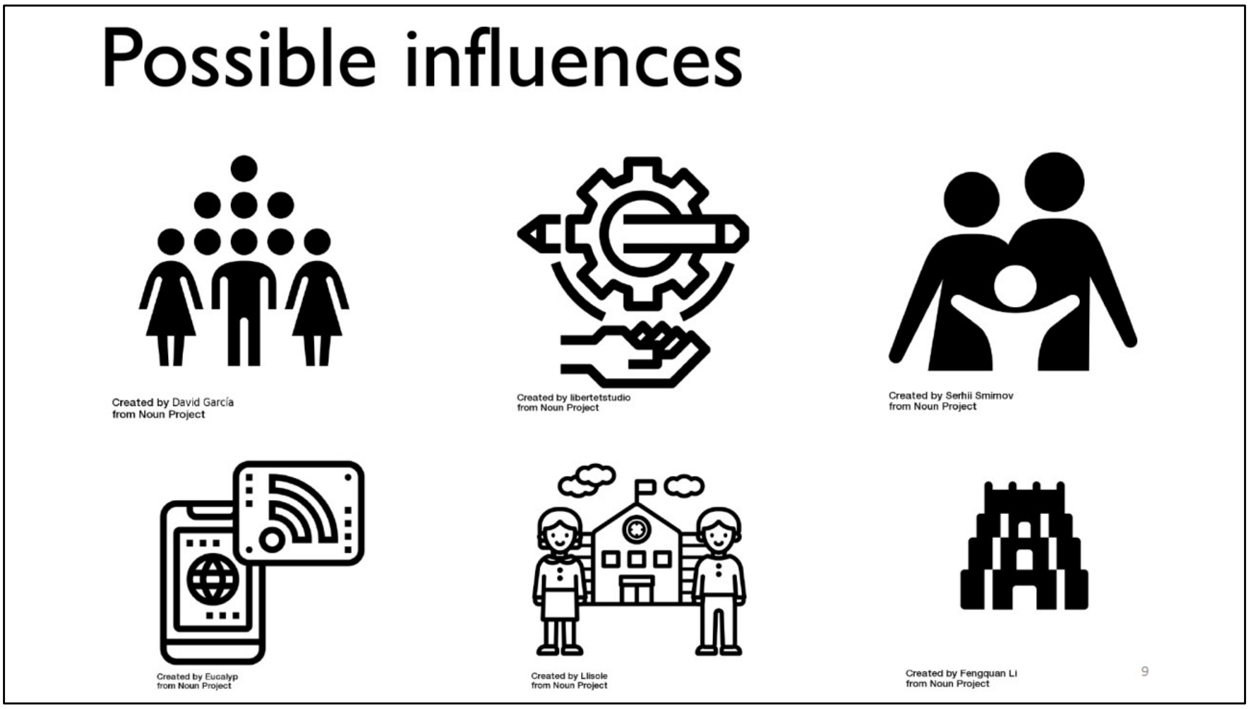

Slide 8

Perspectives	Ideas	Key question
Traditional	Pass on cultural heritage	What are the most important aspects of our cultural heritage that should be preserved?
Experiential	Personal development is the purpose of education, so subject matter will be derived from ordinary life experiences	What experiences will lead to the healthy growth of the individual?
Behavioural	Learning a set of skills that can be observed and measured, emphasis on competencies & processes	At the completion of the curriculum, what should the learners be able to do?
Constructivist	Development of the mind, construction of personal meaning	How can people learn to make sense of the world and to think more productively & creatively?
Structure of the discipline	Development of intellect through disciplinary apprenticeships. Each discipline has a distinctive structure & acquiring these is paramount	What is the structure of the disciplines of knowledge?

1

Slide 9

STEM poses some tricky issues…

- What is/are its disciplinary structure(s)? STEM draws on existing 'disciplines' and did not evolve on its own
- Are there overlaps or contradictions in how these disciplines explain & justify new knowledge claims?
- Is STEM education just the application of knowledge & engaging activities? What is its value proposition? What specifics do you want your economy to focus on?
- There is no 1 "right" model: Thank Goodness & Oh No!

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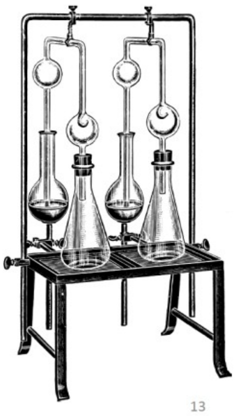
Slide 10

2. General organization of a curriculum



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Slide 11

Curricula can be organized via:

a) Macro & Micro levels
b) Vertical (sequence) & horizontal (scope) dimensions
c) Content presentation types
d) Top-down approaches
e) Bottom-up approaches
f) Project-based approaches

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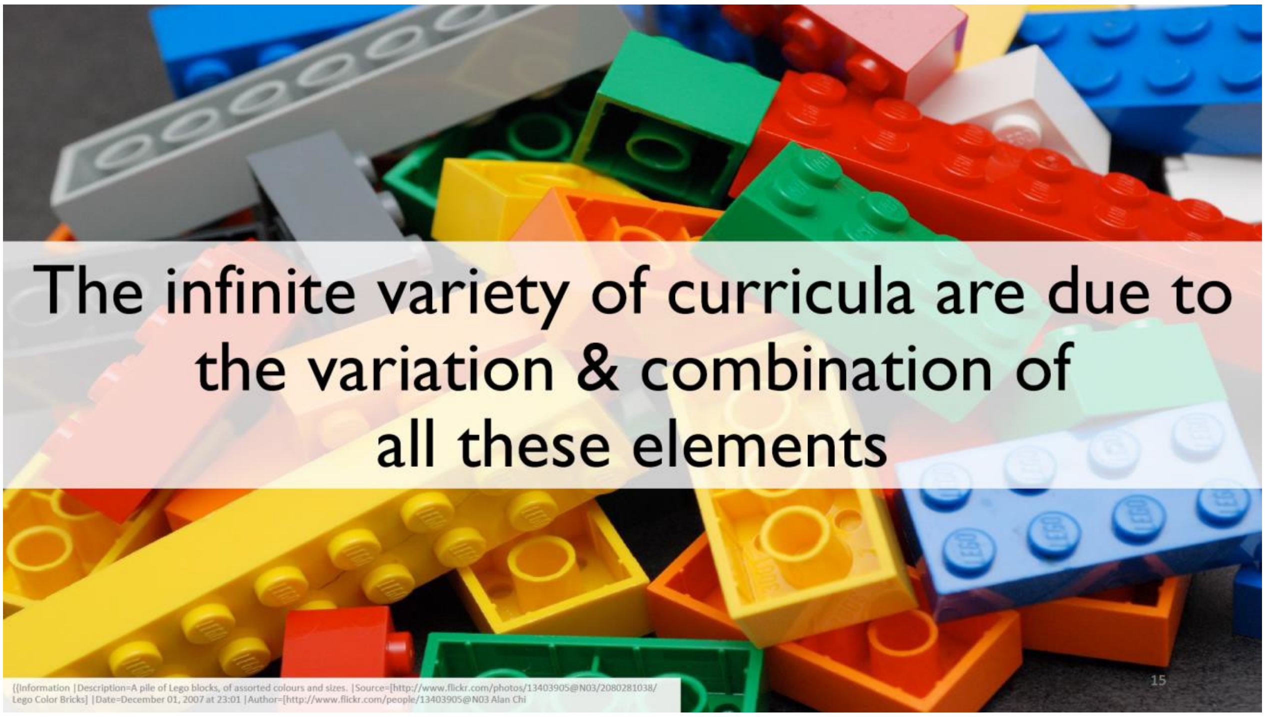
Slide 12



Slide 13

a) Macro & Micro levels

- Macro – broadest level of organization e.g. how courses/topics are located against other courses/topics, whether a program is for UG or postgraduate levels or which university faculty or department "owns" which courses
- Micro – smallest level of organization e.g. the relationship between conceptual ideas or elements (eg assessment & objectives) *within* a course/unit
- Many more in-between levels because macro & micro are <u>relative</u> terms

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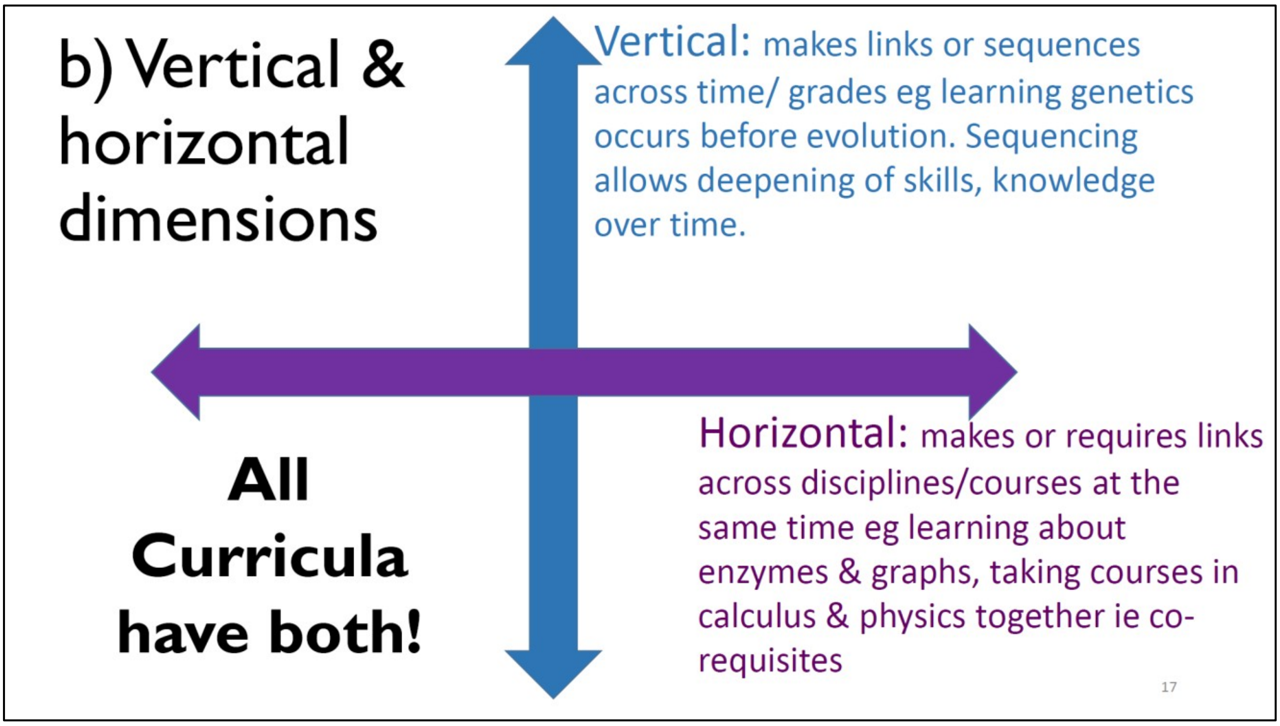
Slide 14



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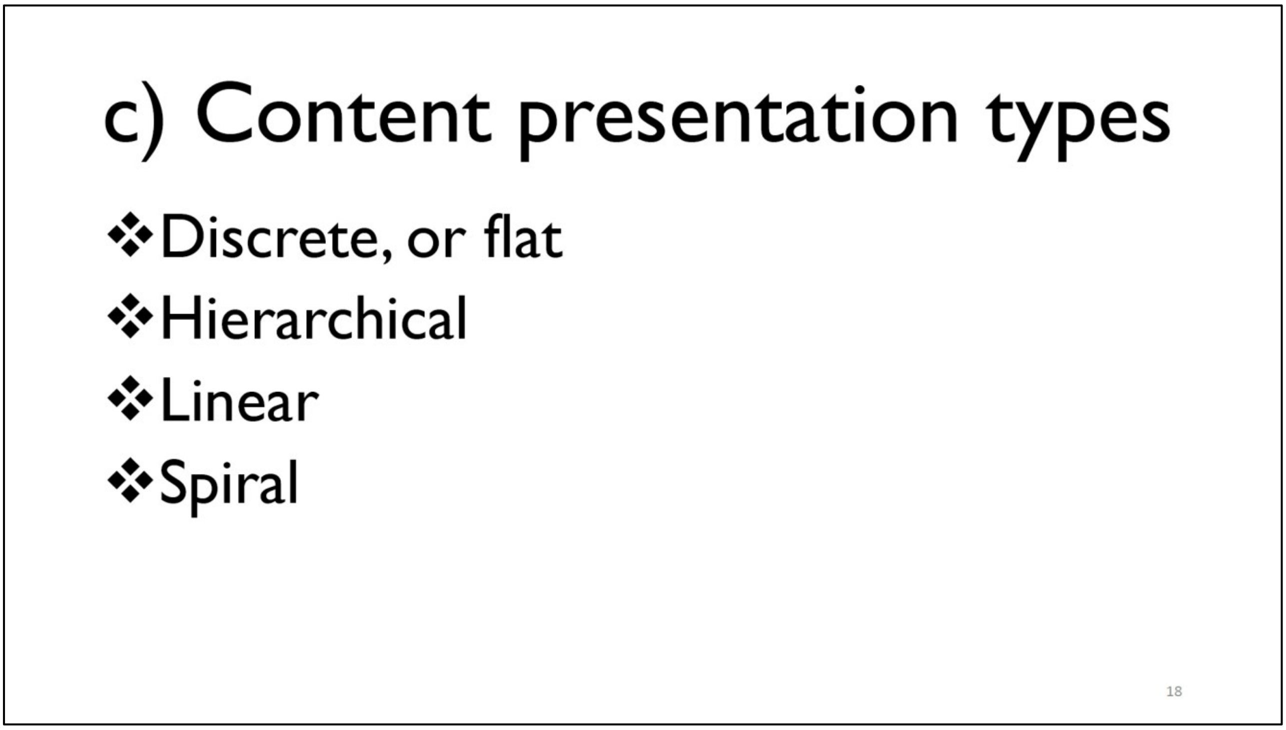

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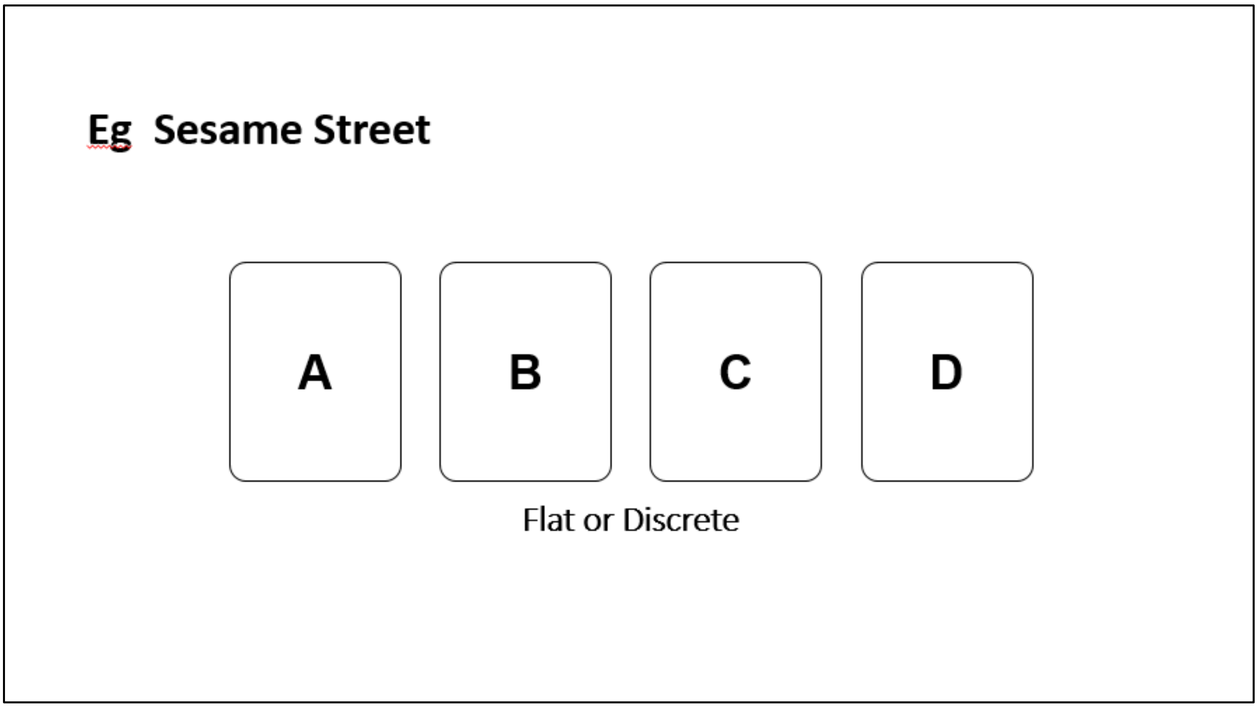

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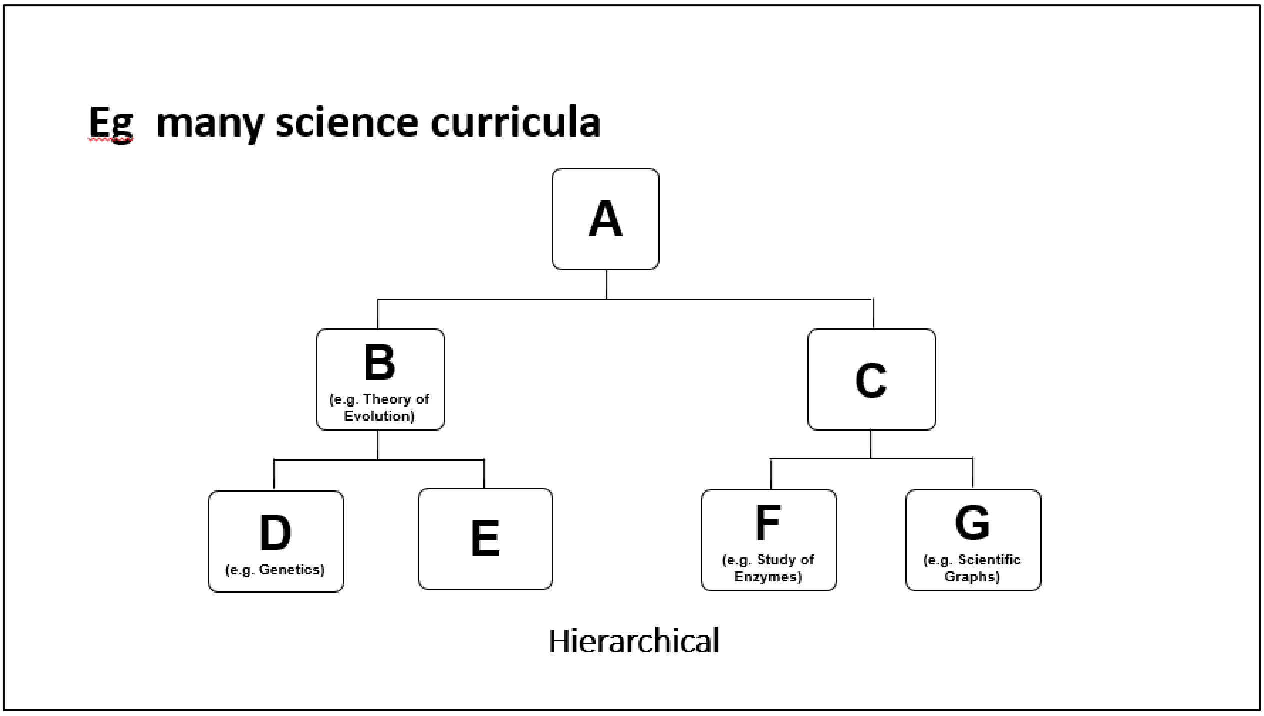

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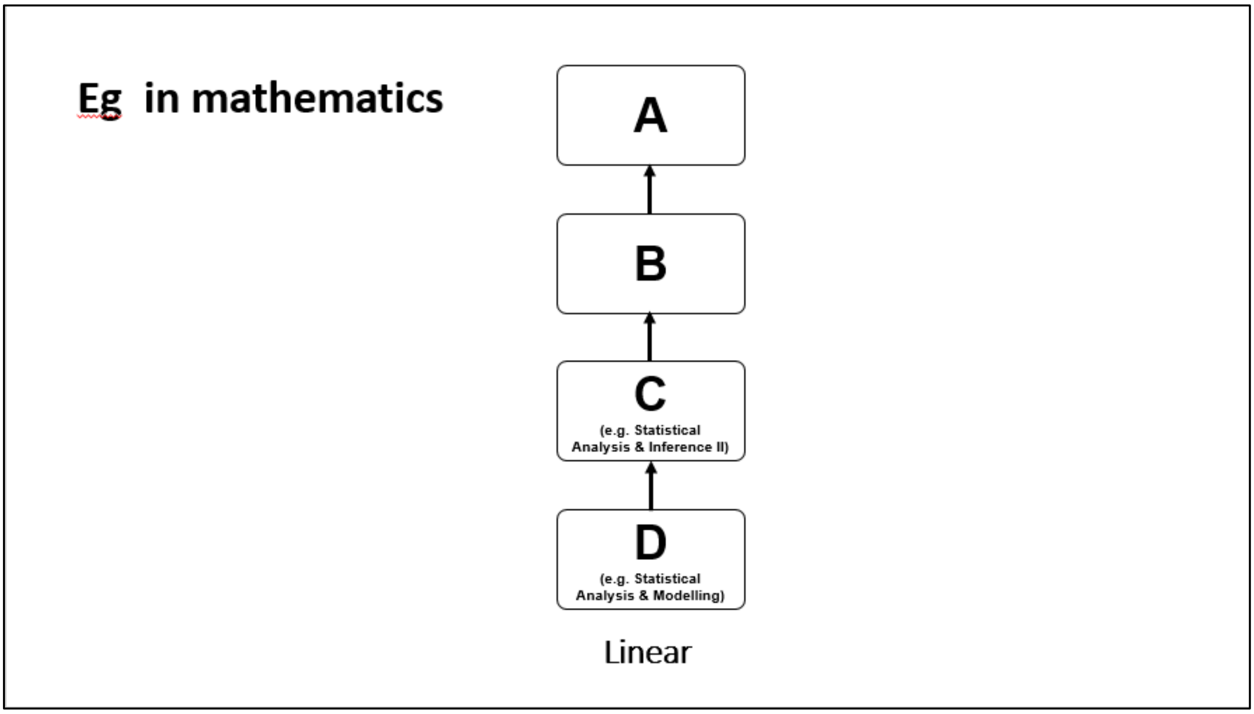

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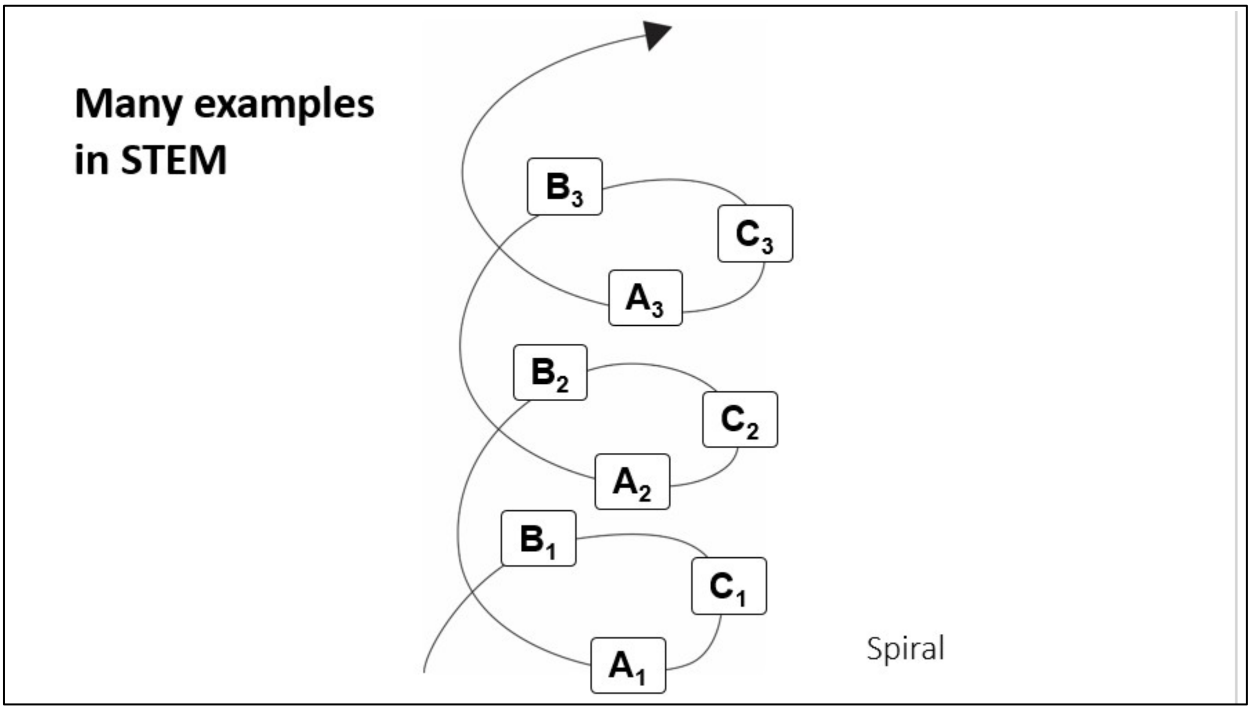

Slide 20

d) Top-down approaches (discipline structure)

e) Bottom-up approaches (how a learner might learnt)

f) Project-based approaches (e.g. themes &/or student-led activities to learn by doing, PBL)

Slide 21

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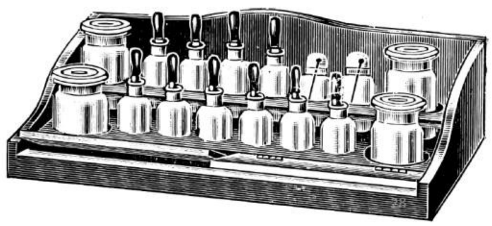
Slide 22

Slide 23

3) Organization of topics/courses for STEM



Slide 24

Topics/courses in a curriculum can be organized by

- Coverage = selection & number of topics/courses intended to be taught
- Focus = number of topics/courses covered within a grade or grade division
- Sequencing of topics/courses = when topics/courses appear & stop over time
- Emphasis = relative emphasis of a topic; more LO or credits in a topic means that there is greater emphasis

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Slide 25

Biology in Singapore (LO across grades & topics)

Topics	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
Diversity	5					
Cell Structure and Organisation Movement of Substances	6		9		12	
Biological Molecules			7		10	
Nutrition in Humans	4		7			
Nutrition in Plants			6			5
Transport in Flowering Plants	3		7			
Transport in Humans	4		8			
Respiration in Humans			8			11
Excretion in Humans				4		
Homeostasis				4		
Co-ordination and Response in Humans				12		
Animal reproduction		10		9		
Plant reproduction				6		
Cell Division Molecular Genetics Inheritance				29	30	
Organisms and their Environment		11		8		
Evolution						12
Diseases & Climate Change						19
TOTAL	22	21	52	72	52	47

NB. Its *one* school subject

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Slide 26

A specialist approach to integrated science

	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Grade 8	Grade 9
3. Plants, fungi	31 (22.0%)	6 (4.3%)	2 (1.3%)	8 (6.0%)	26 (9.6%)		
14. Habits and niches	4 (2.8%)	5 (3.6%)	3 (2.0%)		4.5 (1.7%)		
4. Animals	16 (11.3%)	12 (8.7%)	4 (2.6%)		14.5 (5.4%)		
1. Organs, tissues		3 (2.2%)	6 (4.0%)		35.5 (13.1%)		
15. Biomes and ecosystems		1.5 (1.1%)		14 (10.4%)	15.5 (5.7%)		
9. Life cycles	8 (5.7%)	12 (8.7%)			4 (1.5%)		
13. Interdependence of life		1.5 (1.1%)			13 (4.8%)		
16. Reproduction			16 (10.6%)		35 (13.0%)		
40. Organism sensing and responding			4 (2.6%)		34 (12.6%)		
23. Organism energy handling			3 (2.0%)		16 (5.9%)		
28. Physical cycles				2 (1.5%)	20 (7.4%)		
24. Land, water, sea resource conservation				5 (3.7%)	6 (2.2%)		
35. Cells					19 (7.0%)		
32. Pollution		2.3 (1.7%)	2 (1.3%)	4 (3.0%)	4 (1.5%)		8 (2.0%)
36. Human nutrition					7 (2.6%)	5 (1.4%)	
31. Explanations of physical changes	23 (16.3%)	7 (5.1%)	6.2 (4.1%)	5 (3.7%)		21 (5.9%)	
2. Physical properties of matter	11 (7.8%)	8 (5.8%)	5.2 (3.4%)			43 (12.0%)	
10. Physical changes of matter	10 (7.1%)		3 (2.0%)	6 (4.5%)		11 (3.1%)	
7. Light		16 (11.6%)	2 (1.3%)			38 (10.6%)	
5. Classification of matter			9.5 (6.3%)			34 (9.5%)	
18. Types of forces			14 (9.3%)			47 (13.2%)	
34. Sounds and vibration			10 (6.6%)			27 (7.6%)	
27. Chemical changes of matter			11.2 (7.4%)			37 (10.4%)	
11. Heat and temperature				13 (9.7%)		23 (6.4%)	
26. Atoms, ions, molecules						25 (7.0%)	
19. Weather and climate	18 (12.8%)		5 (3.3%)	13 (9.7%)			43 (10.9%)
21. Magnetism	11 (7.8%)			9.5 (7.1%)			23 (5.8%)
25. Earth in the solar system		14 (10.1%)	5 (3.3%)				9 (2.3%)
20. Planets in the solar system		7 (5.1%)	24 (15.9%)				6 (1.5%)

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Slide 27

A generalist approach to integrated science

	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Grade 8	Grade 9
9. Life cycles	8 (5.6%)	6 (3.8%)					
29. Land forms	6 (4.2%)						
32. Pollution			2 (1.5%)				
30. Material and energy resource conservation				2 (1.4%)			
3. Plants, fungi		28 (17.9%)	11 (8.2%)	1 (0.7%)	5 (2.6%)		
6. Rocks, soil	8 (5.6%)	14 (9.0%)			21 (10.8%)		
7. Light		16 (10.3%)		14 (10.1%)	19 (9.8%)		
4. Animals	24 (16.9%)				5 (2.6%)		
34. Sounds and vibration	15 (10.6%)				11 (5.7%)		
22. Earth's composition		18 (11.5%)			10 (5.2%)		
13. Interdependence of life			8 (6.0%)		7 (3.6%)		
14. Habits and niches			3 (2.2%)		4.5 (2.3%)		
15. Biomes and ecosystems			9 (6.7%)		1.5 (0.8%)		
18. Types of forces					20 (10.3%)		
2. Physical properties of matter	26 (18.3%)	22 (14.1%)		8 (5.8%)	12 (6.2%)	19.5 (10.2%)	
24. Land, water, sea resource conservation	4 (2.8%)	4 (2.6%)			4 (2.1%)	5 (2.6%)	
31. Explanations of physical changes			10 (7.5%)	4 (2.9%)	65 (33.5%)	3 (1.6%)	
37. Building and breaking					3 (1.5%)	10 (5.2%)	
5. Classification of matter	6 (4.2%)	4 (2.6%)	2 (1.5%)	2 (1.4%)		2 (1.0%)	
25. Earth in the solar system	10 (7.0%)			26 (18.7%)		15 (7.8%)	
21. Magnetism	16 (11.3%)			8 (5.8%)		7 (3.6%)	
28. Physical cycles		6 (3.8%)		3 (2.2%)		12 (6.3%)	
8. Electricity				8 (5.8%)		15 (7.8%)	
23. Organism energy handling				5 (3.6%)		15 (7.8%)	
36. Human nutrition				2 (1.4%)		4 (2.1%)	
12. Bodies of water						11 (5.7%)	
26. Atoms, ions, molecules						(23(12.0%)	
11. Heat and temperature			16 (11.9%)			17 (8.9%)	5.5 (2.8%)
20. Planets in the solar system			12 (9.0%)			13 (6.8%)	20 (10.3%)
35. Cells				2 (1.4%)		3 (1.6%)	7.5 (3.9%)
1. Organs, tissues				(17(12.2%		16 (8.3%)	7.5 (3.9%)

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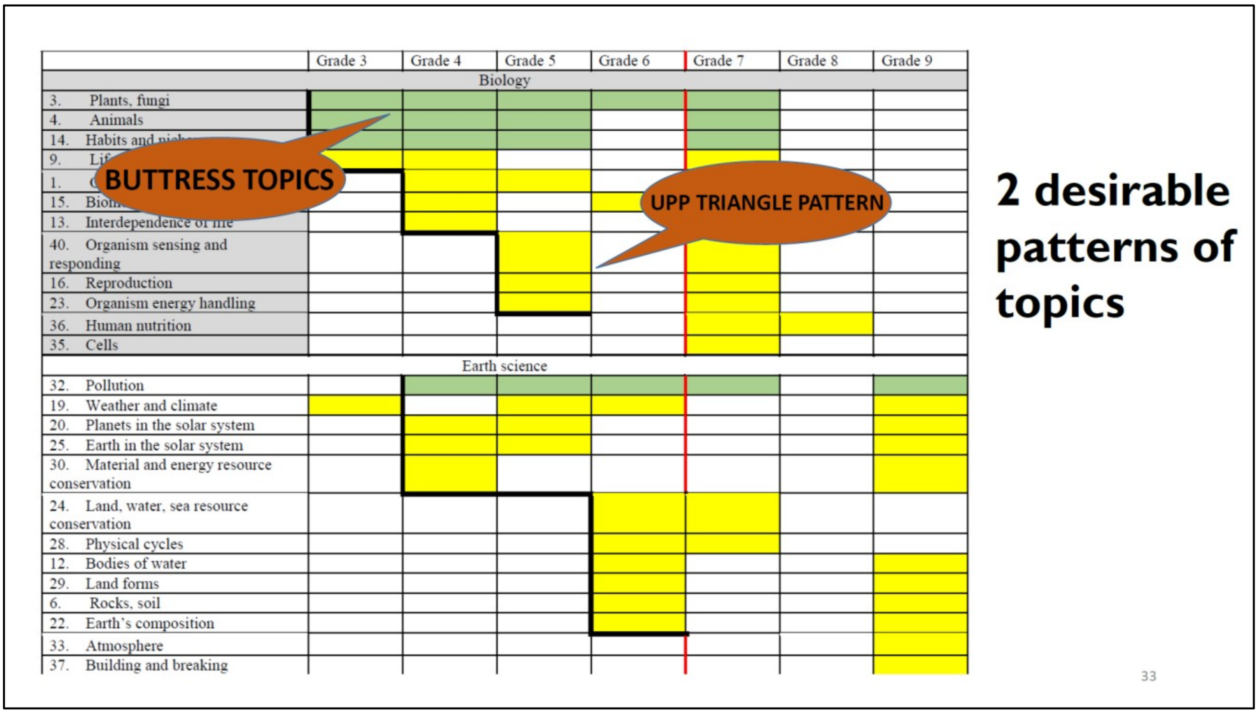

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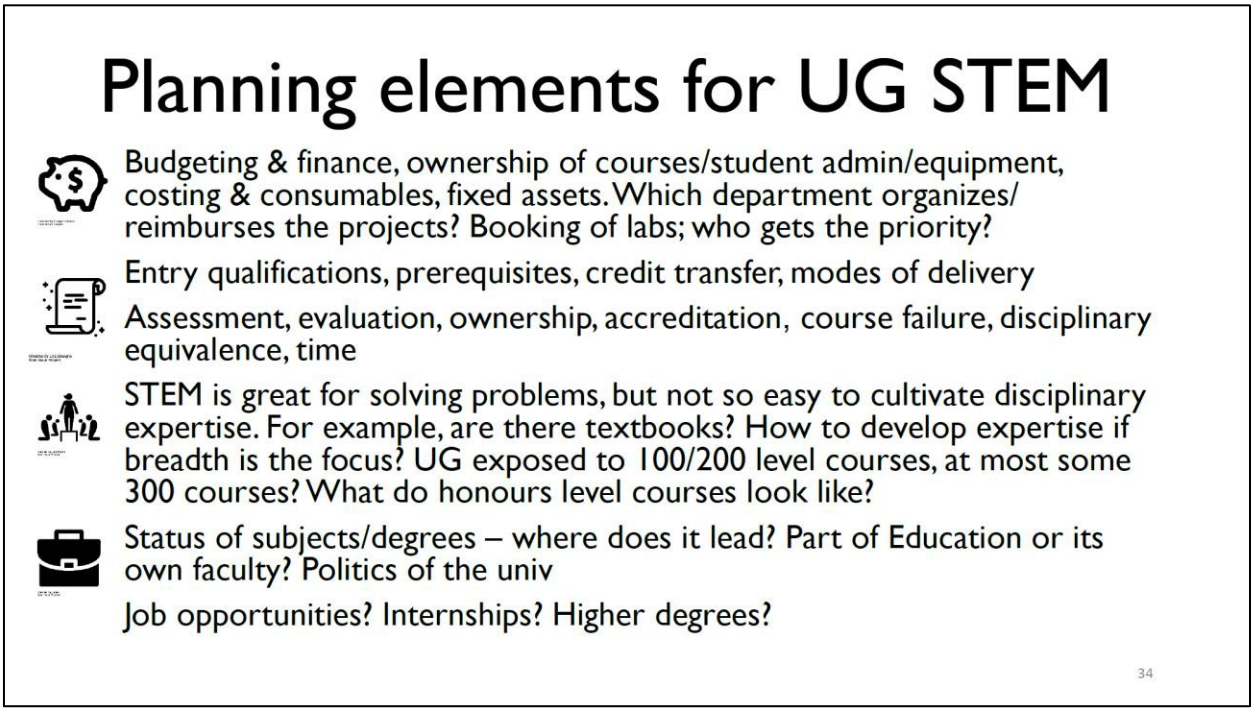

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Multiple Decisions	
Course work components	Projects; mini or capstone
Breadth of disciplines & sub-disciplines, Openness to multiD, interD, transD learning	Specialization of disciplines & sub-disciplines first
Major disciplinary focus, structure of the disciplines	Minor disciplines available, practical, hands-on learning
Formal courses	Co-op & internships
Using/adapting current courses & experiences	Planning de novo courses & STEM experiences
Progressive deepening of subjects/courses	Horizontal emphasis of subjects/courses
Higher choice & agency of learning experiences	Lower choice & agency of learning experiences

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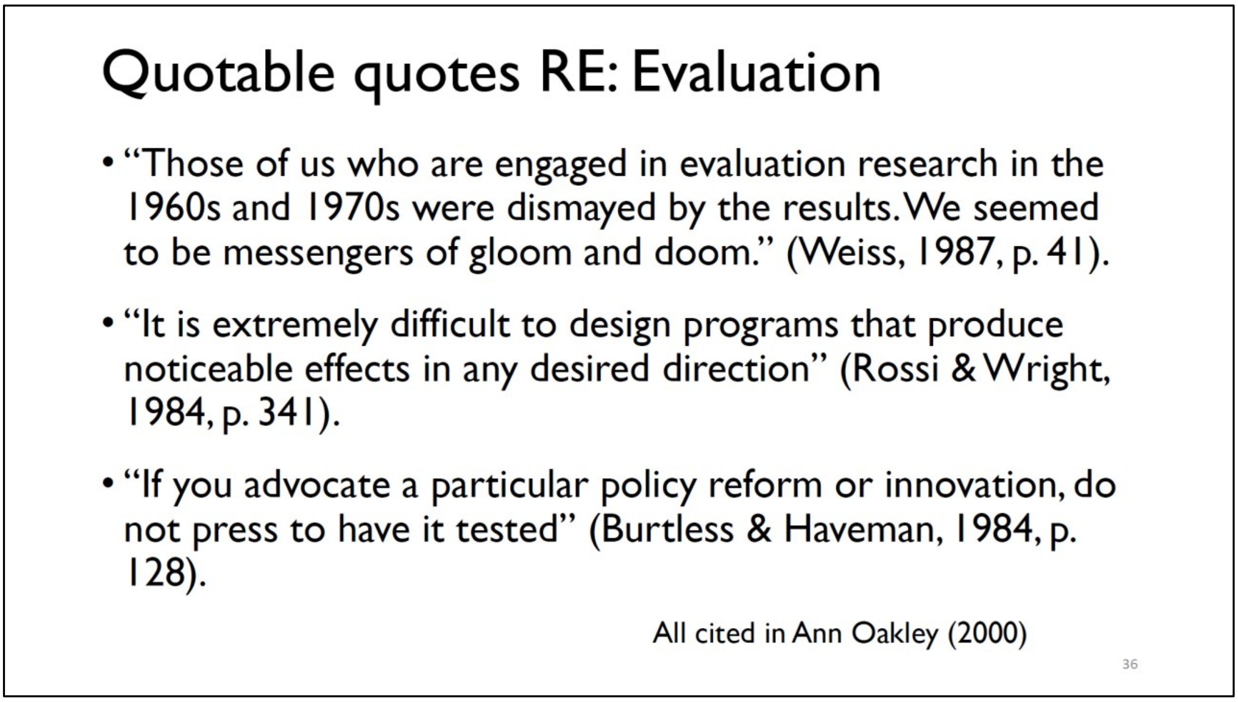

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