Equipping Youth Leaders with Sustainability Mindfulness through STEAM and Design Thinking Approach

Yin-Fah Elliot Lee[1], Tzu-Hua Wang[1], Ming-Tay Foo[2], Kee-Fui Turner Lam[1], Miguel Angel Ortiz-Esparza[3*] and Klinge Orlando Villalba-Condori[4]

[1] *National Tsing Hua University, Taiwan*
[2] *Goshen Consilium Pte. Ltd.*
[3] *Center for Research in Mathematics, Quantum Knowledge City, Zacatecas, Mexico.*
[4] *Universidad Catolica de Santa Maria, San Jose S/N, Arequipa, Perú*

Abstract

Background: The problem statement, with regards to instilling SDG to our youths, is 'how might we elevate our youth's capability to deliver SDG?' This paper explores the use of STEAM (Yakman, 2008) and Design Thinking (IDEO) as an approach towards enabling youths on sustainability and acts as a baseline to designing key competencies for the study. The present study highlights a STEAM-DT workshop for Grade 11/12 students, which took place over 4-day.
Results: With the STEAM-DT approach in the instructional design, it had provided the facilitators with a clear and structured frame in sowing the trans-disciplinary STEAM-DT to the learning. And at the same time, within the 4-day workshop, the students have attained accelerated learning and performance.
Conclusion: STEAM education should be approached beyond a subject/disciplinary standpoint, and instead viewed as a means to develop life skills in learners. By integrating STEAM into the learning curriculum, learners are encouraged to think critically, comprehend complex issues, and create solutions.

Keywords

Sustainability, STEAM, Design Thinking, Interdisciplinary, Competencies

1. Introduction

Education plays a crucial role in shaping the future of our society, and as such, it is essential to explore how education can be effectively designed to prepare the youth for the challenges of the 21st century. It is widely acknowledged that education is not just about acquiring knowledge, but also about instilling values (Weyringer, Patry and Weinberger 2012) in the youth. There are many reasons why this is important. Firstly, values are an essential part of who we are as human beings. They help us make decisions and guide our actions. Secondly, values help us live happy and fulfilling lives. When we have strong values, we are more likely to make choices that lead to positive outcomes for ourselves and others. Finally, values play a crucial role in creating a just and peaceful world (UNESCO, Mobilising Youth Through Global Citizenship and Sustainable Development Education: An impact story from Senegal"). When people have shared values, they are more likely to cooperate with each other and work towards common goals.

With the intention to accelerate the impact of the students learning, the instructional design for the curriculum employs project-based learning (Brassler and Dettmars 2017), STEAM education (Lam, Wang, Vun and Ku 2019), and design thinking (IDEO) approaches. In the learning

CISETC 2023: International Congress on Education and Technology in Sciences 2023, December 04–06, 2023, Zacatecas, Mexico
*Corresponding autor
elliot.lee@lofconsultants.com.sg (Yin-Fah Elliot); tzuhuawang@mx.nthu.edu.tw (Tzu-Hua Wang); foomingtay@gmail.com (Ming-Tay Foo); turner@edu-aequitas.com (Kee-Fui Turner); miguel.ortiz@cimat.mx (M. Ortiz-Esparza); kvillalba@ucsm.edu.pe (K. Villalba-Condori)
0000-0003-3181-5627 (Yin-Fah Elliot); 0000-0002-4085-9851 (Tzu-Hua Wang); 0000-0002-4823-1807 (Ming-Tay Foo); 0000-0003-4027-2505 (Kee-Fui Turner); 0000-0001-8762-5780 (M. Ortiz-Esparza); 0000-0002-8621-7942 (K. Villalba-Condori)

journey, besides the lectures provided by CGS, facilitation (Center and Basilan 2017) and coaching (Green, Grant, Rynaardt 2020) techniques were employed to ensure students get the maximum learning impact (Degtjarjova, Irina & Lapiņa, Inga and Freidenfelds, Davis 2018).

This paper will then discuss the how to create a transdisciplinary of STEAM and DT. Finally, this paper will conclude with a discussion of the implications of the research findings for education policy and practice.

1.1. Theoretical Background: STEM to STEAM education

STEM education stands for Science, Technology, Engineering, and Mathematics. It focuses on teaching students in these four fields, which are crucial for modern-day innovation and advancement. Since the start of the 4^{th} industrial revolution, educators are faced to better equip the youth for future of work (Bernard 2020). In preparing the future workforce, STEAM is gaining popularity over STEM education (Kang and Nam-Hwa 2019). STEAM education includes the arts, making it Science, Technology, Engineering, Arts, and Mathematics. The goal of STEAM education is to add the creative (Kuafman 2018) and critical thinking skills of the arts to the technical knowledge of STEM.

The idea of STEAM education originated from the realization that STEM education alone is not sufficient to prepare students for the demands of the modern workforce. Today's businesses and industries require employees who can think creatively, work collaboratively, and innovate (Hauser et al. 2006) to solve problems.

Integrating the arts into STEM education can help students develop these skills. The arts can enhance STEM learning by providing students with opportunities to explore the creative and design aspects of technology and engineering. Leonardo Da Vinci once said: “Study the science of art. Study the art of science.” (Pasipoularides 2019). The ‘Art’ (A) enables critical thinking (Brookfield 2013), inquiring (Biggs 1998, p127–138), and dialogue (Rapanta and Felton 2022). Additionally, the arts can help students understand the cultural and social implications of scientific advancements.

In addressing the global challenges, it is important that the youth resonate with the SDGs and activate the necessary competencies. Understanding people responses of societal transformation (Hertwig and Ellerbrock 2022) such as their cognition, behaviors, values would likely enable the development of the right solutions for our world. In the 21^{st} century competency (Allen 2013), it is desirable to induct the youth in applying the design thinking (Li and Zhan 2022) principles and methodology.

In summary, STEAM education builds on the foundation of STEM education by integrating arts and design thinking into the curriculum. It aims to produce a new generation of thinkers who can use both their technical and creative skills to solve real-world problems.

1.2. Defining integrated STEAM education

Typically, people look at STEAM from an academic subject. By adopting a broad and interdisciplinary approach, this study aims to uncover the ways in which these disciplines can work together to drive progress and create positive social change. This implied that STEAM was purposefully incorporated into the design thinking process.

Science	Science is the pursuit and application of knowledge and understanding of the natural and social world following a systematic methodology based on evidence (International Association of Engineers 2021). In other words, science is a systematic organization of body of knowledge (The Science Council 2020).
Technology	The word technology comes from two Greek words: techne, meaning "art" or "craft", and logos, meaning "logic" or "reason. In other words, technology is an ascendancy of knowledge, skills, processes, and methodology (Cambridge Dictionary).

Engineering	The term *engineering* is derived from the Latin *ingenium*, meaning "cleverness" and *ingeniare*, meaning "to contrive, devise" (International Association of Engineers 2021). In other words, it is the use of scientific principles to design and build solutions (Wikimedia 2021).
Art	The first meaning of the word *art* is " way of doing " (Collins English Dictionary). The arts are also referred to as bringing together all creative and imaginative activities, without including science (Wikimedia 2021). In other words, it is an ability to reach out to diverse cultures and experiences.
Mathematics	The word *mathematics* comes from Ancient Greek *máthēma* (*μάθημα*), meaning "that which is learnt", "what one gets to know", hence also "study" and "science" (Wikimedia 2021). In other words, it is a systematic treatment of magnitude on relationships between figures and algebra.

By broadening our understanding of STEAM beyond the traditional academic subjects, we can begin to see the ways in which these disciplines intersect and work together to shape our world.

2. Methods

2.1. Curriculum Designers

2.1.1. Competencies that drive STEAM education

Curriculum designers met to re-examine of the abovementioned STEAM definitions and its purposes, a deeper extraction of what are the competencies needed to deliver STEAM. Reviewing of publish journals and authors books have enabled the identification and defining the competency descriptors. The identified competencies include metacognition, inquiry thinking, computational thinking, design thinking, creative communication, and systems thinking, are all critical for effective STEAM education and leadership.

Metacognition refers to the ability to think about one's own thinking and learning processes, which is essential for students to reflect on their progress, identify areas of weakness, and develop strategies for improvement.

Inquiry thinking involves asking questions, investigating, and exploring topics in a systematic and critical way, which is necessary for scientific and technological advancement.

Computational thinking involves breaking down complex problems into smaller, more manageable parts, and using logical and algorithmic thinking to find solutions. This is becoming increasingly important as technology plays an ever-larger role in society.

Design thinking involves a human-centered approach to problem-solving, emphasizing empathy, creativity, and collaboration. It is essential for developing innovative solutions that meet the needs of diverse groups of people.

Creative communication involves using a variety of mediums, including visual arts, music, and language, to express ideas and concepts in engaging and meaningful ways. This is important for conveying complex scientific and technological concepts to non-experts.

Systems thinking involves understanding how different components of a system are interconnected and how changes in one part of the system can have far-reaching effects. This is crucial for addressing complex, real-world problems that require interdisciplinary solutions.

With the use of trans-disciplinary STEAM-DT approach (Figure 1), students attained the SDG knowledge, identified the SDGs that resonated with them, develop problem statement and solution within the 4-day workshop.

		Design Thinking (DT)
	Competency	
STEAM	Metacognition	When people practice metacognition, the act of thinking about their thinking enables them to make greater sense of their life experiences and start achieving at higher levels. https://www.edutopia.org/blog/8-pathways-metacognition-in-classroom-marilyn-price-mitchell
	Inquiry Thinking	Inquiry usually encompasses two interrelated activities—(1) thinking about ideas related to conceptual subject-matter and (2) engaging in activities involving our senses or using specific observational techniques. Dewey, J. (1938). Logic: The theory of inquiry. Henry Holt and Company Inc.
	Learning to learn	Learning to learn is not a single entity or skill, but a family of learning practices that enhance one's capacity to learn. Hargreaves, D. (ed) (2005) About Learning: Report of the Learning Working Group. London, Demos.
	Computational Thinking	Computational Thinking equips people with essential critical thinking which allows them to conceptualise, analyse and solve more complex problems. Through the techniques of decomposition, pattern recognition, algorithm and abstraction, it enables the level of computational thinking. Wing, Jeannette. (2006). Computational Thinking. Communications of the ACM. 49. 33-35. https://doi.org/10.1145/1118178.1118215 Decomposition, pattern recognition, algorithm design, and abstraction.
	Problem Solving	Learning problem-centred knowledge will allow learners to readily harness the relevant knowledge base that is useful to understand and solve specific problems. Bereiter, C. (1992). Referent-centred and problem-centred knowledge: Elements of an educational epistemology. Interchange, 23(4), 337–361.
	Design Thinking	Design thinking is deeply rooted in the constructivist approach to learning. Design thinking consists of a 5-stage process that enables the learners to embrace ambiguity. Collins, H. (2013). Can design thinking still add value? Design Management Review, 24(2), 35–39. Leifer, L., & Steinert, M. (2011). Dancing with ambiguity: Causality behavior, design thinking, and triple-Loop Learning. Information Knowledge Systems Management, 10, 151–173.
	Communication	Effective communication is using the appropriate human senses to impact receivers. Communication impacts people, businesses and relationships. Mellors-Bourne, R., Connor, H., & Jackson, C. (2011). STEM Graduates in Non-STEM Jobs. The Careers Advisory and Research Centre, Department for Business Innovation and Skills. Cambridge, England. Retrieved from http:// www.bis.gov.uk/assets/biscore/further-education-skills/ docs/s/11-770-stem-graduates-in-non-stem-jobs-executivesummary.pdf.
	Creative Thinking	Creativity can be defined as synthesizing previous thoughts and redefining previous thoughts (Bessis 1973). Creative thinking is a way of observing problems or situations from a fresh perspective that means unorthodox solutions (which may look unsettling at first). Besis, P. ve Jaquı, H. (1973). Yaratıcılık nedir? İstanbul: Reklam Yayınları.
	Systems Thinking	Systems thinking enables the development of higher order thinking skills, to understand and address complex, interdisciplinary, real-world problems. York, Sarah & Lavi, Rea & Dori, Yehudit & Orgill, MaryKay. (2019). Applications of Systems Thinking in STEM Education. Journal of Chemical Education. 96. 10.1021/acs.jchemed.9b00261.

Figure 1: Integrated STEAM and DT Descriptions

2.1.2. Sustainable Development Goals (SDGs)

The United Nations' 2030 Sustainable Development Goals (SDGs) are a set of 17 goals (TOHO Gas online) (Figure 2) that aim to promote sustainable development and create a better future for all. The SDGs are a comprehensive framework that addresses social, economic, and environmental factors, and emphasizes the importance of partnerships to achieve sustainable living.

The negative impacts of climate change and unsustainable development have been felt across the globe, and the urgency to act on the SDG agenda has become increasingly clear. Countries and corporations are taking steps to act on this agenda, but more needs to be done. The SDGs are critical for creating a sustainable future for our planet and its inhabitants. The SDGs cover a wide range of issues, including poverty, hunger, health, education, gender equality, clean water and sanitation, renewable energy, and climate action.

SDG mindfulness refers to the awareness and understanding of the SDGs and their impact on our lives and the world around us. It is essential to promote SDG mindfulness among individuals, organizations, and communities to achieve the SDGs' objectives. SDG mindfulness can lead to a shift in behaviour towards more sustainable practices and a more significant commitment to achieving the SDGs. Education plays a critical role in promoting SDG mindfulness and creating a generation of socially responsible and environmentally conscious citizens who will actively work towards achieving the SDGs.

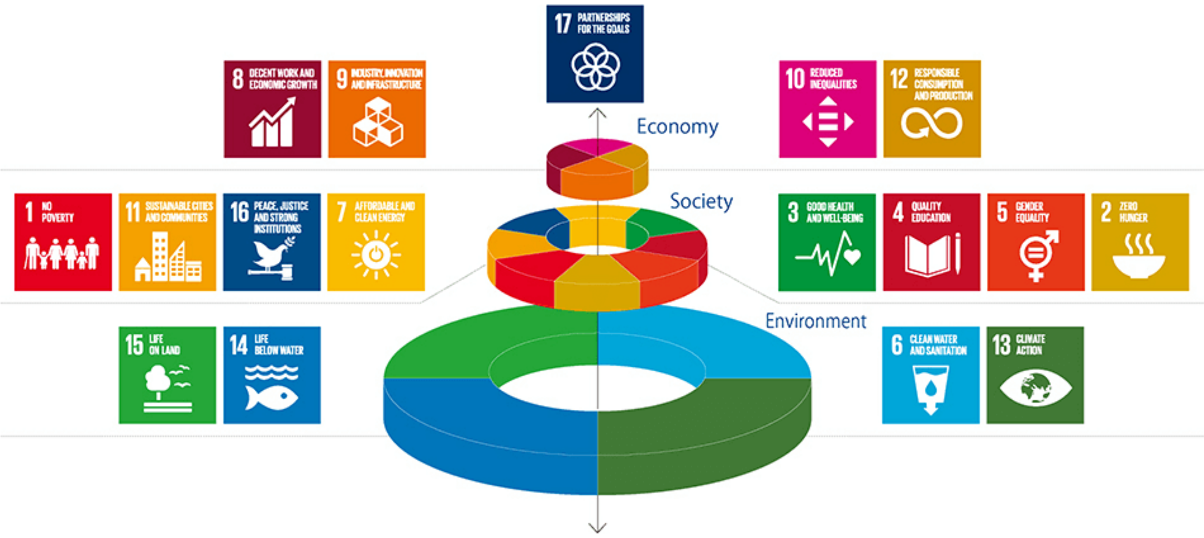

Figure 2: SDGs domains

2.1.3. Design Thinking

Many of the problems we face today are dynamic, multifaceted, and inherently human, and as such, cannot be solved by simply addressing each issue one at a time. Instead, we need to look at the bigger picture and find ways to address multiple issues simultaneously while considering the human element.

Design thinking (DT) is a problem-solving approach that can help us achieve this goal by placing the human experience at the centre of the process. DT emphasizes empathy, collaboration, experimentation, and iteration, all of which can help us better understand and address complex problems.

The Real-Win-Worth It (R-W-W) (George 2008) framework is a useful tool that can be used within the DT process to screen for opportunities and test the viability of new ideas. The R-W-W framework (Figure 3) considers three key factors: Is it real, meaning is there a genuine need for the product or service? Is it a win, meaning can it be profitable or sustainable? And, is it worth it, meaning does it align with the values and goals of the organisation or community?

By using the R-W-W framework, we can ensure that our ideas are not only innovative but also viable and aligned with our overall goals and values. This can help us create solutions that are more effective, sustainable, and impactful.

Figure 3: Real-Win-Worth It

Empathy is a crucial aspect of the Design Thinking (DT) process (Figure 4). By understanding and sharing the feelings and experiences of the user, designers can develop a deeper understanding of their needs, motivations, and pain points. This, in turn, enables them to create products or services that meet the users' needs effectively.

As mentioned, there are various approaches to conducting empathy research (Cuff et al. 2016). Immersing oneself in the user's experience involves experiencing the environment, challenges, and opportunities that the user faces. This can be done through methods such as shadowing or ethnographic research.

Observing the user in their natural context involves watching them interact with their environment and the products or services they use. This approach can provide insights into how the user interacts with their surroundings, the challenges they face, and the solutions they use to overcome them.

Engaging with the user involves interacting with them directly through interviews, surveys, and other forms of communication. This approach can provide insights into the user's thoughts, feelings, and motivations, which can help designers understand their needs and preferences better.

Overall, empathy research is a crucial component of the DT process, and designers must employ multiple approaches to gain a comprehensive understanding of the user.

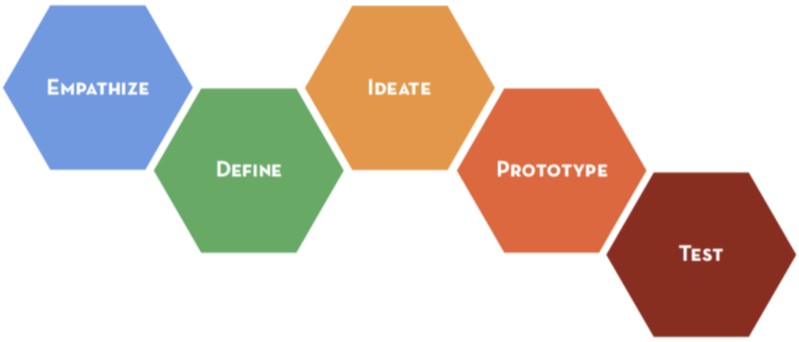

Figure 4: Design Thinking Process

2.1.4. Conceptual framework integrating STEAM and DT

This is the first-time the program instructional design had incorporated STEAM and DT as an approach for Grade 11/12 students; an intended competencies were explicitly used to enable students' learning and performance over a 4-day workshop. Figure 1 has showed the STEAM competencies used in enabling students' application of STEAM model in conjunction with DT approaches. In Figure 5, it shows the hypothesis of applying the STEAM and DT competencies in the instructional design.

For example, when exploring the "Empathize" stage of the DT process, participants may have been encouraged to consider the scientific and technological aspects of their users' needs and experiences. When ideating potential solutions during the "Ideate" stage, participants may have been challenged to think creatively and use artistic skills to visualize their ideas. During the "Prototype" and "Test" stages, participants may have applied engineering and mathematics concepts to refine and improve their solutions.

With the STEAM-DT approach in the instructional design, it had provided the facilitators with a clear and structured frame in sowing the trans-disciplinary STEAM-DT to the learning. And at the same time, within the 4-day workshop, the students have attained accelerated learning and performance.

		Design Thinking (DT)				
	Competency / Evident	Empathize	Define	Ideate	Prototype	Test
STEAM	Metacognition	Metacognition refers to the activities involved in thinking about and forming integrated ideas about oneself and others. *Thinking: 1) Elderly choking on food. 2) Meat turning into soft food for an elderly consumption without being choke?*	Refining the definition of the first problem statement. *Thinking: 1) Why this problem statement? 2) What are we trying to achieve here?*	Thinking about the assumptions, principles, ideas generated and/or solutions. *Thinking: 1) How does this idea integrate with your earlier idea? 2) How would the new idea impact the users and the stakeholders?*	Challenging the appropriateness of the design (hardware, software, processes, etc.). *Thinking: 1) What are the materials you need? 2) Are these materials sustainable? 3) What can be enhanced in the concept to ensure it meets users' needs?*	Thinking on users' experience and adoption, prior, during and post-testing. Testing to pass and testing to fail. *Thinking: 1) Hypothesis testing 2) Concept testing.*
	Inquiry Thinking	Interface with users' experiences. *Techniques: survey questionnaire (qualitative and quantitative), observations, interviews, etc.*	Stakeholders' identification by using stakeholders map, persona, journey map and user story activities, etc.	Ideas generation, synthesize, analyse, and categorisation. *Techniques: brain dump, scamper, world café, etc.*	Optimum ways in building the prototype. *Techniques: proof of concept (hardware, software, flow charts and/or graphical, etc.).* *Example: Solicit POV from industry people.*	To find out much of the users needs are met, easy of use, solutions delivering the desired purpose and results. *Techniques: seek rationale behind the point of views (POV) by stakeholders and industry experts, etc.*
	Learning to Learn	Unlearn, learn and relearn. Listen, observe and feel the users and information shared. Suspend judgment, be curios, inquire and do not provide solutions. *Techniques: adaptive learning, concept mapping, learning styles, peer learning, etc.* *Examples: asking different questions, stakeholders POV revisited in relations to the problem statement, asking questions from different dispositions, challenges assumptions, etc.*		Seek ideas and understanding. *Techniques: source for similar solutions, compare and contrast, leveraging and/or synergise with other domains/disciplines, extract principles, learning, ask industry experts for advice, etc.*	Learning by hands-on. First step of articulation of concepts to application. Through the articulation of concept (using of 5 senses), extract knowledge, skill-sets, attitude need for the solution. *Techniques: each iteration is application of new learning. Trial & Error, Reflective learning.*	Observe and understand users' experiences and POV. Pay attention to new information and how it would be useful for the solution. *Techniques: 1) Industrial experts POV. 2) Check-in with the stakeholders and others.*
	Computational Thinking	Hunting assumptions, checking assumptions and identifying perspectives. 80% energy spend on performing decomposition of the gathered information and 20% on pattern recognition. *Techniques: categorise information into themes, topics, people, etc.*	Classification of users' experience, needs and characteristics. *Techniques: stakeholders' identification, stakeholders map, persona, journey map, user story, etc.*	With the problem intent, generate ideas to meet the needs of the problems and sub-problems. Identify patterns for affinity of ideas. *Techniques: cluster of ideas to propose a solution.*	Proof of concept (POC) and proof of value (POV). Applying Algorithm design and abstraction. *Techniques: value Stream mapping, process flow mapping, etc.*	
	Problem Solving	Knowledge required: Questionnaire design (quant and qual), interview skills, analysis, generate insights (knowledge, skills and attitudes)	Knowledge required: how to write a problem statement, deciding making knowledge, etc.	Knowledge required: Use of a theory or attitude that acts as a guiding principle for behaviour. Knowledge: multi-disciplines, inter-disciplines, trans-disciplines		
	Communication	Build rapport with different users. Adapt sentence structure and terminology for ease of user understanding. *Techniques: questionnaire design, interviews, etc.*	Share different perspectives with multi-disciplinary team members. *Techniques: visual tools (rich picture, journey map, etc.)*	Communication of ideas, features of the ideas and purpose. *Techniques: inquire and articulate responses with receiver's visual/auditory/kinesthetic (VAK) sense.*	Present solution with clarity. *Techniques: unique selling point, benefits and limitations.*	Seek users, stakeholders and experts' POV. *Techniques: face-to-face concept or conceptual prototype presentations*
	Creative Thinking	Observing problems or situations from a fresh perspective that means unorthodox solutions (which may look unsettling at first). *Techniques: connect the dots relation to interviewees' experiences and emotions.*	Connecting and/or incorporating the dots by making sense of the stakeholder's map, journey map, persona, and user story. *Techniques: 1) connect the dots between stakeholders, ideas, characteristics of persona, emotional state. 2) create new inter-relationships.*	Create domains, relationships and story. *Techniques: categorisation, establish inter-relationships, cross-industry learning and ideas, synergise, synthesize multiple ideas to develop impactful solution.*	Creating models and using sustainable resources. *Techniques: visual representation of the message to be presented, illustrator, 3Ds, anticipate users needs and experiences (WoW factors)*	Developing test sets. Simulate user environment. Testing to gather more ideas for solution enhancement (next MVP). *Techniques: multi-faceted measurements, modifications, Math model.*
	Systems Thinking	Working with assumptions, principles, relationships and processes. *Techniques: questions about the system effect, value system, motivators.*	Connecting and/or incorporating the dots by making sense of the stakeholder's map, journey map, persona, and user story. *Techniques: ecosystem effect, casual loop, time effect and cause & effect.*	Identify the co-relations between solutions. *Techniques: inter-relationships and unintended consequence.*	Examine and ensure solution is addressing the problem with systems in mind. *Techniques: sustainable Development Goals (SDGs), material science, environmental science.*	Testing to understand the systems behavior (system boundary). *Techniques: unintended consequences, time effect ana adoption level.*

Figure 5: Integrated STEAM and DT Hypothesis

The use of a rubric (summative and formative assessments) can help to ensure that assessments are consistent and fair, and can also provide clear guidelines for students or participants to follow.

The Bloom's Taxonomy, which was first published in 1956 by Benjamin Bloom and his colleagues, is a framework for categorizing different levels of learning. It is often used as a basis for creating assessment rubrics, with different levels of understanding and skill being mapped onto specific categories within the taxonomy.

Assessment for learning refers to assessments that are designed to provide feedback to students or participants, with the goal of helping them to improve their understanding or skills. Assessment of learning (Bloom, B. et al. 1971), on the other hand, refers to assessments that are used to measure or evaluate what students or participants have learned.

By using a standardized rubric that is based on Bloom's Taxonomy, you can help to ensure that both assessment for learning and assessment of learning are aligned with the goals of the workshop and the level of understanding or skill that is being targeted. Figure 6 shows the assessment rubric and Figure 7 shows the Industry Expert comments on the student's project presentations.

Aspiring Leaders for a Sustainable Future Program 02/2021

Group Name : ______________________

Scoring Rubric (50 MARKS)

CRITERIA	EXCEEDS EXPECTATION	MEETS EXPECTATION	APPROACHING EXPECTATION	BELOW EXPECTATION
MARKET NEEDS AND OPPORTUNITIES	Excellent assessment of target customer needs, market size and market gaps.	Good assessment of target customer needs, market size and market gaps.	Fair assessment of target customer needs, market size and market gaps.	Poor assessment of target customer needs, market size and market gaps.
10 MARKS	*8 - 10*	*6 - 7*	*4 – 5*	*BELOW 4*
SOLUTION AND CONCEPT PROTOTYPE	Excellent solution and unique concept.	Good solution and unique concept.	Fair solution and unique concept.	Poor solution and unique concept.
15 MARKS	13 – 15	11– 13	7 – 10	BELOW 7
COMPETITORS ANALYSIS AND GO-TO-MARKET STRATEGIES	Excellent assessment of competitive analysis, strategic go-to-market action which capitalize on the inherent strength of the market needs and gaps.	Good assessment of competitive analysis, strategic go-to-market action which capitalize on the inherent strength of the market needs and gaps.	Fair assessment of competitive analysis, strategic go-to-market action which capitalize on the inherent strength of the market needs and gaps.	Poor assessment of competitive analysis, strategic go-to-market action which capitalize on the inherent strength of the market needs and gaps.
10 MARKS	*8 - 10*	*6 - 7*	*4 – 5*	*BELOW 4*
FINANCIALS	Comprehensive understanding of the timeline, resource management, production and fulfillment. Comprehensive understanding of cost, revenue and capital requirement till breakeven.	Good understanding of the timeline, resource management, production and fulfillment. Good understanding of cost, revenue and capital requirement till breakeven.	Fair understanding of the timeline, resource management, production and fulfillment. Fair understanding of cost, revenue and capital requirement till breakeven.	Poor understanding of the timeline, resource management, production and fulfillment. Poor understanding of cost, revenue and capital requirement till breakeven.
5 MARKS	4 – 5	3 – 3.5	2 – 2.5	Below 2
PITCHING QUALITY	Presenters speak with high level of confidence and engage the judges with excellent use of visual aids. The pitch is compelling and is delivered within the allotted time.	Presenters speak with good level of confidence and engage the judges with good use of visual aids. The pitch is adequately compelling and is delivered within the allotted time.	Presenters speak with fair level of confidence and engage the judges with basic use of visual aids. The pitch is somewhat compelling and is delivered within the allotted time.	Presenters speak with low level of confidence and could not engage the judges. The pitch is not compelling and is not delivered within the allotted time.
10 MARKS	*8 - 10*	*6 - 7*	*4 – 5*	*BELOW 4*

Panel Scoring: ____________________

Figure 6: Assessment Rubric

Panel comments:

Clear concept.
Well thought out.
Data survey: good job.
Why buy their products - good question.
Well-thought out survey.
Engaging last presenter.
Question: didn't explain how to jump from protein to final product.

Figure 7: Assessment-Pannel comments

2.2. Treatment and control classroom

2.2.1. Implementing the integrated STEAM and DT practices

The present study highlights a Design Thinking workshop for Grade 11/12 students, which took place over half-day Friday, three full Saturdays, and a half-day Tuesday, from 19th February 2021 to 9th March 2021. The workshop comprised 19 specially chosen participants from an international school, who attended lectures at a renowned university in Singapore. The lectures were delivered by professors from the Centre for Governance of Sustainability (CGS), who expounded on the why, what, and impact of SDGs on our lives. Dialogue sessions, held in English and Mandarin, were incorporated after each lecture, aimed at fostering a deeper understanding, particularly for the Mandarin speaking students.

Following the initial lectures, the subsequent three Saturdays were dedicated to the DT journey, utilizing a dynamic learning approach (Huang et al. 2020) supported by schoolteachers (Figure 8).

Figure 8: Workshop in action

3. Results

As mentioned earlier, the study also incorporated a standardized evaluation rubric, designed to evaluate student performance week-to-week and project performance at the conclusion of the workshop (Figure 9). Furthermore, the student's work was assessed by three external industry experts, who provided qualitative comments (Busetto et al. 2020) on the study's outcomes.

Figure 9: Work group presentation

Overall, the study presents a well-structured and planned approach to examining the impact of Design Thinking on Grade 11/12 students. The incorporation of industry experts and the use of a standardized evaluation rubric enhances the validity of the findings. The present study contributes to the existing literature on Design Thinking, providing valuable insights into its application in a Grade 11/12 educational context.

4. Discussion

At the end of a 4-day workshop, students were able to accelerate their learning and apply their knowledge effectively during the four-day workshop. The integration of STEAM competencies and DT can indeed bring about accelerated learning and impact to students' learning, as it provides a holistic approach to problem-solving and encourages creativity and innovation.

However, it is also important to consider the instructional design and delivery approach in the class to ensure that all students can benefit from the workshop. It is understandable that some students may find the process overwhelming, and adjustments may be needed to ensure that the learning environment is conducive to all learners.

4.1. Limitation of integrated STEAM and DT practices

Integrated STEAM and DT practices have become increasingly popular in education and industry in recent years. However, there are some limitations to these practices that should be considered:

- Implementation Challenges: Integrating STEAM and DT practices requires significant collaboration and coordination among educators, administrators, and industry partners. This can be challenging to achieve, particularly in schools or organizations with limited resources and support.
- Lack of Teacher Training: Many educators lack the necessary training and experience to effectively integrate STEAM and DT practices into their curricula. This can result in ineffective or incomplete implementation of these practices.
- Standardization: The increasing emphasis on standardized testing and assessment can make it difficult to integrate STEAM and DT practices into existing curricula. This can limit opportunities for interdisciplinary learning and creative problem-solving.
- Equity: The implementation of STEAM and DT practices may also be limited by issues of equity, particularly in terms of access to resources and opportunities. For example, schools in low-income areas may have less access to the technology and materials necessary to implement these practices effectively.
- Assessment: The assessment of STEAM and DT practices can be challenging, particularly given their interdisciplinary nature. Traditional forms of assessment may not be well-suited to evaluating the complex skills and knowledge developed through these practices.

Overall, while integrated STEAM and DT practices offer many benefits, their implementation can be challenging and may require significant investment in resources and training. In addition, it is important to recognize and address potential limitations in order to ensure that these practices are accessible and effective for all learners.

As for the limitations of the research paper, it is true that the number of students was limited, and the scaffolding of the competencies used may differ from another trainer. Further studies can explore the design and use of STEAM competencies and its relationship to each of the DT processes in more detail, and on a larger scale to provide more comprehensive insights.

Finally, the dynamics of the learning and impact may indeed change if the workshop is conducted for a longer period or extended beyond the four-day duration. This may be worth exploring in future studies to provide a more comprehensive understanding of the impact of the workshop on students' learning outcomes.

5. Conclusion

In conclusion, STEAM education should be approached beyond a subject/disciplinary standpoint, and instead viewed as a means to develop life skills in learners. By integrating STEAM into the learning curriculum, learners are encouraged to think critically, comprehend complex issues, and create solutions. Additionally, coupling STEAM with Design Thinking has shown potential in preparing learners for the volatile, uncertain, complex, and ambiguous environment of the future.

Ultimately, the goal of education should be to create sustainable development in learners, and STEAM education is an important tool to achieve this. As the saying goes, "If you give a man a fish, you feed him for a day. If you teach a man to fish, you feed him for a lifetime." By teaching learners the skills and competencies necessary to create solutions to real-world problems, we empower them to be agents of change in their communities and beyond.

5.1. Availability of data and materials

The data sets are available from the corresponding author upon reasonable request.

5.2. Abbreviations

CGS:	Centre for Governance and Sustainability
DT:	Design Thinking
MIT:	Massachusetts Institute of Technology
R-W-W:	Real-Win-Worth It
SDG:	Sustainable Development Goals
STEAM:	Science Technology Engineering Art Mathematics
UNESCO:	United Nations Educational, Scientific, and Cultural Organization

References

[1] "About IAENG". iaeng.org. International Association of Engineers. Archived from the original on January 26, 2021. [Accessed: 31-Dec-2022].

[2] Anbumozhi, V. (2017). Ensuring ASEAN's sustainable and resilient future. In A. Bavieraand and L. Maramis (eds), ASEAN @ 50 Volume 4: Building ASEAN Community: Political-Security and Socio-cultural Reflections, p. 309-323. Available: https://www.eria.org/ASEAN_at_50_4B.7_ Anbumozhi_final.pdf.

[3] Ares Pasipoularides, Emulating Leonardo da Vinci (1452–1519): the convergence of science and art in biomedical research and practice, Cardiovascular Research, Volume 115, Issue 14, 1 December 2019, pp.181–183, Available: https://doi.org/10.1093/cvr/cvz275.

[4] Bereiter, C. Referent-centred and problem-centred knowledge: Elements of an educational epistemology. Interchange 23, pp.337–361 (1992). https://doi.org/10.1007/BF01447280.

[5] Bessis, P. ve Jaquı, H. (1973). Yaratıcılık nedir? İstanbul: Reklam Yayınları.

[6] Bloom, B. et al. (1971), Handbook on Formative and Summative Evaluation of Student Learning, McGraw-Hill Book Co., New York.

[7] Brassler, M., Dettmers, J. (2017) How to enhance interdisciplinary competence-Interdisciplinary Problem-Based Learning versus Interdisciplinary Project-Based Learning. Interdisciplinary Journal of Problem-Based Learning, vol 11 (2). Available: https://doi.org/10.7771/1541-5015.1686.

[8] Busetto, Loraine & Wick, Wolfgang & Gumbinger, Christoph. (2020). How to use and assess qualitative research methods. Neurological Research and Practice. 2. 14. 10.1186/s42466-020-00059-z.

[9] C. Dictionary, "Technology," Cambridge Dictionary. [Online]. Available: https://dictionary.cambridge.org/dictionary/english/technology. [Accessed on 02-Jan-2023].

[10] Cambridge, England. Retrieved from http:// www.bis.gov.uk/assets/biscore/further-education-skills/ docs/s/11-770-stem-graduates-in-non-stem-jobs-executivesummary.pdf. [Accessed on: 10 January, 2023].

[11] Collins, H. (2013). Can design thinking still add value? Design Management Review, 24(2), pp.35–39. Available: https://doi.org/10.1111/drev.10239.

[12] Cuff, Benjamin & Brown, Sarah & Taylor, Laura & Howat, Douglas. (2016). Empathy: A Review of the Concept. Emotion Review. 8. pp.144-153. 10.1177/1754073914558466.

[13] Day, George. (2008). Is it real? Can we win? Is it worth doing? Managing risk and reward in an innovation portfolio. Harvard business review. 85. pp.110-20, 146.

[14] Degtjarjova, Irina & Lapiņa, Inga & Freidenfelds, Davis. (2018). Student as stakeholder: "voice of customer" in higher education quality development. pp.388-398. 10.21272/mmi.2018.2-30.
[15] Dewey, J. (1938). Logic: The Theory of Inquiry. New York: Henry Holt and Company. [Accessed on: 10 January, 2023]. Available: https://www.scirp.org/(S(czeh2tfqw2orz553k1w0r45))/reference/referencespapers.aspx?referenceid=1423937.
[16] E. Britannica, "Art," Encycl. Br., 2020.
[17] eduTOPIA website. Metacognition: Nurturing Self-Awareness in the Classroom. [Accessed on: 10 January, 2023] Available: https://www.edutopia.org/blog/8-pathways-metacognition-in-classroom-marilyn-price-mitchell.
[18] Green, S., Grant, A. M., & Rynsaardt, J. (2020). Evidence-Based Life Coaching for Senior High School Students. Coaching Researched, pp.257–268. Available: https://doi.org/10.1002/9781119656913.CH13.
[19] Hargreaves, D. (ed) (2005) About Learning: Report of the Learning Working Group. London, Demos. Available: http://dera.ioe.ac.uk/id/eprint/23216.
[20] Huang, Zhenya & Liu, Qi & Chen, Yuying & Wu, Le & Xiao, Keli & Chen, Enhong & Ma, Haiping & Hu, Guoping. (2020). Learning or Forgetting? A Dynamic Approach for Tracking the Knowledge Proficiency of Students. ACM Transactions on Information Systems (TOIS). 38. pp.1-33. 10.1145/3379507.
[21] Hauser, John & Tellis, Gerard & Griffin, Abbie. (2006). Research on Innovation: A Review and Agenda for Marketing Science. Marketing Science. 25. 10.1287/mksc.1050.0144.
[22] IDEO Design Thinking, Design Thinking Defined, [Accessed on 19 October, 2022]. Available: https://designthinking.ideo.com.
[23] IDEO, What is design thinking?, Available at: https://www.ideou.com/blogs/inspiration/what-is-design-thinking [Accessed: 21-Dec-2022].
[24] J. Allen, "Skills for the 21st century: Implications Dutch education," Higher Education: Recent Trends, Emerging Issues and Future Outlook. pp.1-40, 2013.
[25] J. Biggs, "The role of metacognition in enhancing learning," Aust. J. Educ., vol. 32, no. 2, pp.127–138, 1988.
[26] K.-F. T. Lam, T.-H. Wang, Y.-S. Vun, and N. Ku, "Using DDMT Teaching Model to Cultivate Critical Thinking in a STEAM Classroom," in International Congress on Education and Technology in Sciences, 2019. pp.47–57, 2019.
[27] Kang, Nam-Hwa. (2019). A review of the effect of integrated STEM or STEAM (science, technology, engineering, arts, and mathematics) education in South Korea. Asia-Pacific Science Education. 5. 10.1186/s41029-019-0034-y.
[28] Kaufman J. Creativity as a Stepping Stone toward a Brighter Future. J Intell. 2018 Apr 4;6(2):21. doi: 10.3390/jintelligence6020021. PMID: 31162448; PMCID: PMC6480761.
[29] Leifer, L., & Steinert, M. (2011). Dancing with ambiguity: Causality behavior, design thinking, and triple-Loop Learning. Information Knowledge Systems Management, 10, pp.151–173. Available: http://dx.doi.org/10.3233/IKS-2012-0191.
[30] Li, T.; Zhan, Z. A Systematic Review on Design Thinking Integrated Learning in K-12 Education. Appl. Sci. 2022, 12, 8077. https://doi.org/10.3390/ app12168077
[31] Loh, L., Thomas, T., & Wang, Y. (2017). Sustainability Reporting and Firm Value: Evidence from Singapore-Listed Companies. Sustainability, 9, 2112R., Center, S., & Basilan, B. (2017). Facilitation Techniques towards Enhancing K- 12 English Language Proficiency of Different High Schools: Basis for Intervention Program. Asia Pacific Journal of Education, Arts and Sciences.
[32] M Bernard, Information-Enterprise Tech, 'We need STEAM, Not STEM Education, To Prepare Our Kids for 4th Industrial Revolution", Forbes. [Online]. Available: https://www.forbes.com/sites/bernardmarr/2020/01/15/we-need-steam-not-stem-education-to-prepare-our-kids-for-the-4th-industrial-revolution/?sh=373e550e55fb.

[33] Mellors-Bourne, R, Connor, H & Jackson, C 2011, STEM graduates in non-STEM jobs, BIS research paper, no. 30, Department for Business, Innovation and Skills, London, [Accessed on: 20 January, 2023] Available: http://www.bis.gov.uk/assets/biscore/further-education-skills/docs/s/11-771-stem-graduates-in-non-stem-jobs.
[34] Ralph Hertwig, Dagmar Ellerbrock, Why people choose deliberate ignorance in times of societal transformation, Cognition, Volume 229, 2022, 105247, ISSN 0010-0277, https://doi.org/10.1016/j.cognition.2022.105247.
[35] Rapanta, C., Felton, M.K. Learning to Argue Through Dialogue: a Review of Instructional Approaches. Educ Psychol Rev 34, pp.477–509 (2022). Available: https://doi.org/10.1007/s10648-021-09637-2.
[36] S. Brookfield, "Teaching for critical thinking," Handb. Res. Teach. Learn. K …, 2013.
[37] "The arts definition and meaning". Collins English Dictionary. Archived from the original on 11 July 2017. [Accessed on 02-Jan-2023].
[38] The Science Council, "Our definition of science," The Science Council, 2020. [Online]. Available: https://sciencecouncil.org/about-science/our-definition-of-science/. [Accessed on 02-Jan-2023].
[39] TOHO GAS, "Contribution to Sustainable Development Goals (SDGs) [Online]. Available: https://www.tohogas.co.jp/lang/en/approach/eco/eco-09/. [Accessed on 02-Jan-2023].
[40] U. Nations, "Education | Department of Economic and Social Affairs," United Nations. [Online]. Available: https://sdgs.un.org/topics/education. [Accessed: 21-Dec-2022].
[41] U. Nations, "Young People's Meaningful Involvement Vital for Advancing Sustainable Development Goals, Speakers Stress as Youth Forum Conclude" |Meetings Coverage and Press Releases | Economic and Social Council, United Nations. [Online]. Available: https://sdgs.un.org/topics/education. [Accessed: 27-Dec-2023].
[42] UNESCO, "Mobilising Youth Through Global Citizenship and Sustainable Development Education: An impact story from Senegal" [Online]. Available: https://en.unesco.org/sites/default/files/mobilizing_youth_through_global_citizenship_and_sustainable_development_education_9.pdf
[43] UNESCO, "UNESCO with, by and for youth" [Online]. Available: http://www.unesco.org/new/en/social-and-human-sciences/themes/youth/youth-definition/.
[44] Weyringer, S., Patry, JL., Weinberger, A. (2012). Values and Knowledge Education. In: Alt, D., Reingold, R. (eds) Changes in Teachers' Moral Role. Moral Development and Citizenship Education, vol 6. SensePublishers, Rotterdam. Available: https://doi.org/10.1007/978-94-6091-837-7_14.
[45] Wikimedia, "Engineering," Wikipedia, 2021. [Online]. Available: https://en.wikipedia.org/wiki/Engineering. [Accessed: 02-Jan-2023].
[46] Wikimedia, "Mathematics," Wikipedia, 2021. [Online]. Available: https://en.wikipedia.org/wiki/Mathematics. [Accessed on 02-Jan-2023].
[47] Wing, Jeannette. (2006). Computational Thinking. Communications of the ACM. 49, pp.33-35. Available: https://doi.org/10.1145/1118178.1118215.
[48] Yakman, Georgette. (2008). STEAM Education: an overview of creating a model of integrative education.
[49] York, Sarah & Lavi, Rea & Dori, Yehudit & Orgill, MaryKay. (2019). Applications of Systems Thinking in STEM Education. Journal of Chemical Education. 96. 10.1021/acs.jchemed.9b00261.I. Editor (Ed.), The title of book one, volume 9 of The name of the series one, 1st. ed., University of Chicago Press, Chicago, 2007. doi:10.1007 3-540-09237-4.