SySTEAM mini-conference

August 14th & 15th, 2025

Virtual/online

Pre-reading packet

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Children's after school club on Systems Thinking and Sustainability

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Abstract. Systems thinking is deemed to be a key competence to systems engineering professionals and other professionals. Systems thinking is for all ages and can help solve world problems. This author believes and has demonstrated in this paper that you can start as early as primary school with children aged 7-8 years old. The paper provides the details of a club run in the summer term (last term of the year) of a year 2 of primary school in the UK in a way that it can be re-used widely. There were 8 sessions held focused on Sustainability around the school with the use of the systems thinking habits. The sessions were well attended and enjoyed by the students. These sessions can be extended further if needed or make it more concise as per the curriculum in the school implementing the club.

Introduction

Systems Thinking is arguably the most important skill a systems engineering professional should have/develop. Even more importantly, this way of thinking is key for so many other professions in the world and therefore it is key to be developed. But where do we start? Many efforts on Systems Thinking target university students. This author believes that we can start introducing this topic as early as primary school.

Education system in the UK

Children in the UK start primary school at age 4 in reception class . During reception, children are still in the Early Years Foundation Stage (EYFS). Good quality reception provision is child centered, allowing children to follow their own interests as they develop. It follows a holistic approach that focuses on the child as a whole, developing themselves as a learner and an individual. There is a great emphasis put on the characteristics of effective learning, allowing children to gain the skills that underpin the rest of their schooling and development. At this stage children should be allowed to explore and learn from a range of enabling environments which provides learning opportunities in a wide range of areas. When children have completed reception, they move into Key Stage 1 (KS1) and then Key Stage 2 (KS2). Here children have lessons based on specific subjects. A good Primary curriculum should be broad and inspiring, encouraging a love of learning that can be taken with the children throughout their education.

The year groups for primary school are listed below. The infant age range (KS1) is from age 5 to 7. The Junior age range (KS2) is from age 7 to 11. (Bright World, 2022)

Children in the UK are encouraged to try a range of subjects early in their education. In this way they get to learn from a broad and balanced curriculum, giving them a wide range of learning opportunities to suit their particular learning style

In order to influence a Science Technology Engineering and Maths (STEM) career path and STEM subjects in the UK, one has to start in primary school. Here they can begin to develop an understanding of the STEM subjects but also gain the skills that underpin learning and investigation in these areas.

The idea for a systems thinking club came to the author as a way to enhance her daughter's learning at the school. STEM subjects are taught regularly, but this allows children to experience a different way of thinking and learn a range of vocabulary and understanding they would not normally come into contact with during their KS1 education.

Systems Thinking

The systems thinking concept originated in 1956, when Professor Jay Forrester founded the Systems Dynamic Group at MIT's Sloan School of Management. [Ben Lutkevich 2020]

Systems thinking is a holistic approach to analysis that focuses on the way that a system's constituent parts interrelate and how systems work over time and within the context of larger systems. The systems thinking approach contrasts with traditional analysis, which studies systems by breaking them down into their separate elements. Ben Lutkevich proposes systems thinking can be used in any area of research and has been applied to the study of medical, environmental, political, economic, human resources, and educational systems, among many others. It can be used by all ages.

Jim Waters, founder of the Waters Corporation, a publicly-traded, analytical science solutions company, attended sessions on system dynamics led by Dr. Jay Forrester of MIT. This spurred Mr. Waters' interest in system dynamics as an important life skill. Mr. Waters and Dr. Forrester conversed about the importance of integrating these ideas into a Kindergarten to year 12 (K-12) environment. Mr. Waters became interested in the potential of investing in K-12 environments to foster learning about complex, dynamic systems. [Waters Center 2022]

The activities used in this paper were inspired in part by the activities on the [Waters Center 2022] website but also from their knowledge sharing events. The author was inspired by the ice-breaker activities that are regularly shared through the online events by Waters Center that gave life and made the club fun.

Another key resource that had to be ordered directly from the United States was the pack of Systems Thinking Cards. We ordered 5 packs for use in the club.

Figure 1. Systems Thinking Habit Cards (Waters Center Card Page 2022)

Sustainability

The author chose to give the club a practical spin and chose sustainability as the topic on which to practice the systems thinking skills. And what better than the United Nations Sustainability goals to use for the ideation process.

The Sustainable Development Goals are a call for action by all countries – poor, rich and middle-income – to promote prosperity while protecting the planet. They recognize that ending poverty must go hand-in-hand with strategies that build economic growth and address a range of social needs including education, health, social protection, and job opportunities, while tackling climate change and environmental protection. (UN 2022)

Figure 2. UN Sustainability Goals (UN 2022)

Lesson plans and feedback

The after school club was planned for Monday's after class for about 30 minutes with planned content amounting to about 25 minutes to allow for transfer to the classroom and to dismiss students to their parents/carers.

We decided to open the club only to year 2 students, in KS1, which are the oldest in the infant school. As we planned for regular systems thinking rounds and to allow each student one minute to speak each, it was deemed that a class of 10 students would be optimal to run the club.

The club was run by the author, a STEM Ambassador and Mother of a student, and a Teacher at the school. The club was listed like all other clubs to parents to select it for their children. The parents make their choice on a paper form and the school distributes the places in order of preference and some arbitration if oversubscribed.

The club stirred some interest and was booked to full capacity with no-one being rejected.

Detailed planning and thoughts after each session are described in the following sections.

1st session

The first session was held as planned on the 9th of May.

<table>
<tr><td colspan="2">Activity: Systems Thinking Introduction</td></tr>
<tr><td>PLAN</td><td>ACTUAL</td></tr>
<tr><td>
● Introduce Systems Thinking as a way that people can think to solve problems that are complex (like protecting the environment). And we will look at some of the habits of a Systems Thinker using some cards.
● Why systems thinking? Because lasting, impactful change occurs when we understand a system fully — what's happening, what's working, what isn't — and when we have the tools to change the system to produce desired results.
● Video: https://waterscenterst.org/why-systems-thinking?tab=benefits
● Introduce the Systems Thinking habits cards: https://thinkingtoolsstudio.waterscenterst.org/cards
● Distribute 2 X 14 cards in sets of 2 or 3 to the 10 children - ask them to find the pair for their cards and discuss in pairs the meaning of the card and the related questions for a few minutes and then share the cards to the others.
● Do the exercise of interlacing fingers, look at the thumb, which one is at the top? Now interlace them the opposite way around. How does that feel? Which cards could be applied to this situation?
● Introduce the sustainable goals https://youtu.be/0XTBYMfZyrM and https://www.youtube.com/watch?v=e2S9wf5oVT4

Conclusion/Next Steps:
● Brainstorm together how the school is contributing to the goals?

Resources:
● (Walter Center Card Page 2022) and (UN Sustainable Goals 2022) /child
● 4-5 packs of the Systems Thinking Habits cards.
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● After a short introduction to the young people we started debating about systems and the fact that systems can be made up not only from machined parts (e.g. car system) but also from humans interacting (e.g. going to the doctor) or both (e.g. healthcare system).
● Then we explored the benefits of system thinking (scroll at the 4 main benefits - (Waters Center, ST Benefits 2022))
● Next we presented the 14 cards (https://thinkingtoolsstudio.waterscenterst.org/cards) by splitting the cards into several identical sets of 3-2 cards distributed , discussing them in small groups and then discussing them all in the big group.
● Then we did a little exercise - making a fist with both hands and then trying to change the fist so that the other thumb was on top. We all recognised that the opposite way around was weird! So we identified a few cards that explained what we did here (e.g. change perspective).
● Finally we watched a short video about the UN sustainability goals (https://youtu.be/0XTBYMfZyrM) and they all chose to be explorers for this week and identify sustainability problems around the school (with the help of the teacher) that we can apply our newly learned systems thinking skills.
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</table>

WHAT WENT WELL	*IDEAS FOR IMPROVEMENT*
• Young people engaged in the activity, • They were curious about the activity • They really enjoyed the practical exercise.	• Language on the cards was a bit complicated, should we have a version of the cards for young people? • The discussion around the 14 cards was a bit lengthy and difficult to follow, we realized it half way through and focused the presentation on the screen with the cards there and that caught everyone's attention. I would recommend going through the cards on the screen and calling the young people who had that card forward to the screen to explain it. • After a second look at the video about systems thinking we decided not to show it and instead focusing on the 4 icons showing the benefits and then move on with the cards. • We ran out of time at the end and only showed the short sustainability goals video. It is not so catchy for a young audience and it would be good to find one that is a bit more fun and educational.

2nd session

Second session was held as planned on the 16th of May.

Activity: Systems thinking Round Table	
PLAN	***ACTUAL***

- Summary from last time? What do we still remember?
- Display/have the UN Goals next to each child the UN Sustainability goals
- Make a circle together with teacher and facilitator
- Introduce the rules (simplified from (SESA 2022)):
  - 1 person takes a turn in speaking at a time
  - That person has the teddy
  - We all listen to what they have to say and don't interrupt
  - Safe place - what is said in the circle stays in the circle (not speaking about it in the playground, ok to share with parents)
  - Go around the circle twice with a small break
  - Each has 45 seconds on both rounds
- Introducing the Topic - "Sustainability topic around the school = where can we improve?"
- Half way through activity: Hold pointer fingers front with 5 children facing 5 children and holding the long stick at waist height. Challenge is to put the stick down :). (See demonstration at https://youtu.be/YuZbNvYPzFM) .See cards time delays, test assumptions, successive approximations.

Conclusion/Next Steps:
- Next time we will look at the big picture and make connections cards and will draw the big picture for the problems identified.

Resources:
- Timer (phone timer)
- A ball or something for the person speaking
- A long stick (for the middle activity)

- Experimented with the systems thinking round table where each child had a turn to speak uninterrupted about what improvements they want to see in school
- Sustainability and the UN goals minded
- Did 2 rounds and the idea was to build on each other's ideas.
- Used a teddy, Jigsaw Joe (used also in another class), to mark the person talking and passing it onto the next person when finished.
- Between the two rounds we did the activity where the children (all 10 of them) held a long ruler on their 2 index fingers and the task was to put the ruler down together.
  - Somehow when they were all 10 the ruler only went up
  - We tried counting to 3 and all simultaneously bringing the fingers down and that was somewhat successful.
  - Then we split them into 2 teams of 5 and tried again and this time it was much better.
  - We remembered the system thinking card on successive approximations and how this may relate to the activity we just did.
- Ideas from the systems thinking rounds:
  - Improve early birds building
  - Leaving school
  - Improve playground equipment
  - Bigger swimming pool
  - Use of less paper
  - Have more trees in the school
  - Not picking on Nature
  - Have Adventure closer to school (bus ride quite long)
  - All toilets not working
  - Reloading soap in toilet not often enough
  - Have less stiff taps
  - Some taps not working
  - Pet going to vet
  - Turn off taps
  - More art
  - Electric buses
  - Stop picking plants/ not annoy them
  - Library only on Friday and sometimes missing it- more Library sessions
  - Drinking more water

<table>
<tr><th>WHAT WENT WELL</th><th>IDEAS FOR IMPROVEMENT</th></tr>
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- All respected each other, didn't interrupt and waited their turn
- Each contributed with one idea.

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- The timer was irrelevant as they (unlike adults) kept their ideas short and to the point and were much faster than the clock.
- Maybe take a bit more time to discuss cards linked to the activity as discussed only one.

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3rd session

Third session was held as planned on the 23rd of May.

<table>
<tr><td colspan="2">Activity: Big Picture and Meaningful Connections Cards and drawing</td></tr>
<tr><td>PLAN</td><td>ACTUAL</td></tr>
<tr><td>

- Summary from last time? what do we still remember?
- Introduce the Systems Thinking habits cards we will focus in the session - Big Picture / Meaningful connections: https://thinkingtoolsstudio.waterscenterst.org/cards
- Watch the “a guide to diagraming” to see how we brainstorm about problems and create the big picture: http://www2.open.ac.uk/openlearn/diagramming/index.html
- Use coloured pens and paper to create the big picture for the ideas.

Conclusion/Next Steps:

- Have a look at the big picture created
- At break: If multiple groups can connect the problems somehow? Do they impact each other?

Resources:

- Take the 2 cards (big picture and making connections) from the 4-5 card sets and distribute them to the children: 1 card for every child.
- Big sheets of paper
- Coloring crayons

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- Each child was given one of the 2 cards
- Children watched the first 5 minutes of the video regarding the big picture
- Their ideas were split into 5 big topics and the children chose between these topics and started drawing their big pictures. Below is the topic and associated big picture.

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

Improve school facilities

Improve early birds building / Improve playground equipment/ Bigger swimming pool/ All toilets not working/ Reloading soap in toilet not often enough/ Have less stiff taps/Some taps not working / Electric busses

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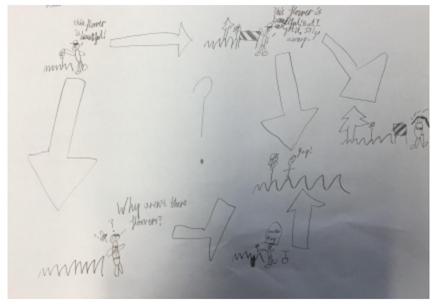
12 RESPONSIBLE CONSUMPTION AND PRODUCTION

Improve school practice and policy

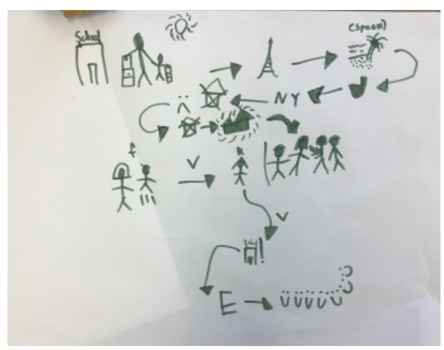
Use of less paper / Drinking more water / No picking on Nature



10 REDUCED INEQUALITIES

Connection with school even after leaving it

Leaving School



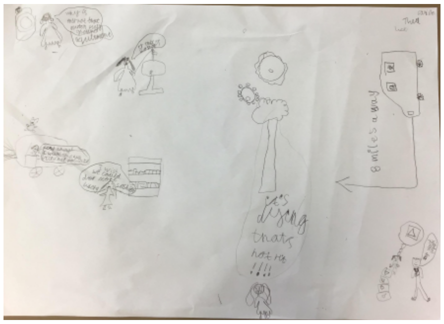
15 LIFE ON LAND

Protect and enhance nature in and around school

Have more trees in the school / Not picking on Nature / Stop picking plants/ not annoy them

Enhanced learning opportunities

Improve playground equipment / Improve early birds building / Have Adventure closer to school (bus ride quite long) / More art / Library only on Friday and sometimes missing it- more Library sessions



- Half time into the session the children were encouraged to look at the other big pictures and see if there are any connections with the one they were working on.

WHAT WENT WELL	***IDEAS FOR IMPROVEMENT***
• All children picked a topic and expressed the problem using drawings	• The sessions worked according to plan. If children were older some stencils could be provided to make drawings neater and more legible

4th session

The 4th session was held as planned on the 6th of June after half term.

Activity: Systems thinking Round Table	
PLAN	***ACTUAL***

• Summary from last time? what do we still remember?
• Have the big pictures from last time to hand
• Make a circle together with teacher and facilitator
• Introduce the rules (simplified from (SESA 2022))
  ○ 1 person takes a turn in speaking at a time
  ○ That person has the teddy
  ○ We all listen to what they have to say and don't interrupt
  ○ Safe place - what is said in the circle stays in the circle (not speaking about it in the playground, ok to share with parents)
  ○ Go around in circle twice with a small break
  ○ No timing this time
• Introducing the Topic - "Thinking about the bigger picture - what influences sustainability at the school"
• Halfway through activity: At break - watch the monkey business, and see if they notice the monkey - https://youtu.be/IGQmdoK_ZfY. Intro to ladder of inference (tunnel vision) what are the opposite cards?
Conclusion/Next Steps:
• Next time we will look at the big picture and make connection cards and will draw the big picture for the problems identified.
 	
Resources:
• A toy for the person speaking
	• Experimented with the systems thinking round table where each child had a turn uninterrupted to speak about what they described in their big picture and what problem they saw in the school.
	• Did 2 rounds and the idea was to build on each other's ideas.
	• Used a teddy, Jigsaw Joe (used also in another class), to identify the person talking and passing it onto the next person when finished.
	• In-between the two rounds we watched the monkey business video https://youtu.be/IGQmdoK_ZfY where the children had a counting task and the idea was to see if they observed the monkey.
	  ○ Surprisingly, most of the children observed the monkey
	  ○ Also, some of the children refused to play the counting game so they clearly observed the monkey coming and going
	• Two themes consolidated from the systems thinking round: pollution and taking care of nature (plants, animals, gees, flowers)

WHAT WENT WELL	***IDEAS FOR IMPROVEMENT***
• This time for the systems thinking round we did not use the timer as last time children expressed themselves in short sentences • Surprisingly for the first turn the children spoke for the full minute or even more and were eager to express their ideas • When asked to summarize the topic they want to work on the children consolidated quickly the two topics and some children passed	• N/A

5th session

The 5th session was held on 13th June.

<table>
<tr><td colspan="2">Activity: Start practicing some Systems thinking</td></tr>
<tr><td>PLAN</td><td>ACTUAL</td></tr>
<tr><td>
● Summary from last time? What do we still remember?
● Have our big picture with us.
● Show the cause and effect, long term consequences and consider an issue fully https://thinkingtoolsstudio.waterscenterst.org/cards
● Systems Thinking a cautionary tale: https://youtu.be/17BP9n6g1F0
● Brainstorm together on possible actions for our issues. Use the questions on cards to help analyze them
● Have a moment to share the results and close
Conclusion/Next Steps:
● Next time, Systems Thinking Round table, focusing on solutions and how they would benefit school. Also focus on Systems thinking cards through Buck activity.

Resources:
● System Thinking Cards
● Big Pictures sheets
</td><td>
● Children sat on the carpet with big picture drawings in front of them
● Reminded all others about what they were and why they had chosen them.
● Again discussed the impact of the issues and why they had been chosen.
● Showed the ‘big picture’ and ‘cause and effect’ cards
● Children thought of solutions for the problems they had on their ‘big picture’ sheets, in groups
● We then discussed the possible outcomes of these solutions and recorded
● As we were focusing on cause and effect, we also spoke about how these solutions may bring their own problems
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<tr><td>WHAT WENT WELL</td><td>IDEAS FOR IMPROVEMENT</td></tr>
<tr><td>
● Children were able to discuss their ‘big picture’ issues with each other.
● All were listening carefully to each other's ideas.
● Children were able to come up with some solutions for the problems that they had identified.
● We we able to discuss the positive outcomes of these solutions - bearing in mind the cause and effect relationship
● We were able to discuss if these solutions may lead to any addition issues - again referencing cause and effect
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● If we had more time children could have perhaps drawn their solutions onto the big picture drawing. This would have allowed them to spend more time considering them and they would have been there in addition to their initial drawings
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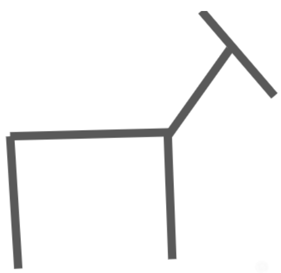
6th session

The 6th session was held on 20th June.

<table>
<tr><td colspan="2">Activity: Systems thinking Round Table</td></tr>
<tr><td>PLAN</td><td>ACTUAL</td></tr>
<tr><td>
● Summary from last time? What do we still remember?
● Introduce the systems thinking round table rules (simplified from (SESA 2022))
● Topic - “Thinking about the actions that we need to take, how will they positively impact the school and school life?"
● each child will have 1 minute to say something on the topic for round 1
● At break - have 5 items of same length, make buck out of them

○ “I have a horse named Buck. He is a traveling horse as he is always on the move. Buck looks like this (draw on chart paper or show on slide if virtual):
○ Use your five sticks to make your own Buck.
○ Because Buck likes to travel so much, I have a challenge for each group.
○ You are only allowed to move one stick to make Buck travel in a different direction. Let me know if you have any questions.”
○ Give people time to struggle a bit as this can be challenging. After some time, you can encourage people to stand up and travel around the table as well to see Buck from a variety of perspectives. Once a group figures it out, instruct them to use their Habits cards to identify which Habits helped them achieve success. Allow others to work on the challenge.
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● Introduced the systems thinking round table rules, as with previous sessions
● Again used Jigsaw Jo for the individual who was speaking
● Completed two rounds of systems thinking round tables where children were given a chance to speak uninterrupted.
● Today we were focusing on how the changes that we decided during earlier sessions could positively impact school life and our school community.
● In between the rounds children completed the Buck activity in groups
● We used rulers to set up the buck character.
● Children worked in small groups to complete this
● Initially they were unable to do so but enjoyed the task and were all enthusiastic to have a go
● Through discussion and perseverance one group initially completed the challenge of making ‘Buck’ change direction.
● The other groups gained confidence from this and became more active in moving the sticks/rulers.
● Eventually through help from other groups all children were able to work as a collective and each group completed their task
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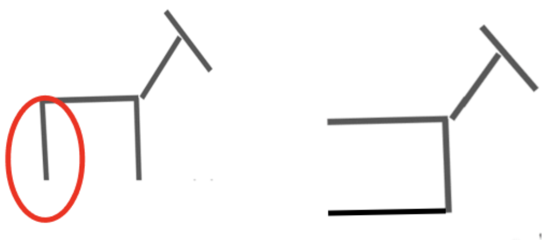
- Depending on your allocated time (estimated 10 minutes for groups to work on the challenge), ask for the whole group's attention and either have a small group share their answer or you can show it on chart paper or a slide if virtual.
- Answer:



- Debrief:
  - What strategies did your group use to help Buck travel in a different direction?
  - What were barriers to your success?
  - Which Habits of a Systems Thinker could be applied to this challenge?
  - What connections can you make between this experience and other challenges you might have in your work or life?
- then each child will have an additional 1 minute to build on what has been said for round 2

Conclusion/Next Steps:

- Have a moment to reflect on what was said and close.

Resources:

- A toy for the person speaking

WHAT WENT WELL	***IDEAS FOR IMPROVEMENT***
● Children were able to speak more confidently than during previous sessions ● Less children now passed when it was their turn ● Most children were able to link their ideas/changes to their initial problem/big	● At times, a couple of the children found it more difficult to link between the issues they have identified, the changes they would like to make and how this links to a change that could be made related to their school life.

picture and were able to consider how a change may influence their school life. ● All children were respectful and listened carefully to each other's ideas ● Children really enjoyed the 'Buck' activity and showed great teamwork	

7th session

The 7th session was held on 27th June.

Activity: Action plan ideas	
PLAN	***ACTUAL***
● Arrange for a meeting with the school to present the ideas and get feedback on them. ● They can show their ideas big picture and ideas for improvement **Conclusion/Next Steps:** ● Have a moment to reflect on the feedback **Resources:** ● All materials they have been working on.	● Initially the children had some time to recap what they had done and the ideas they had come up with in previous sessions. They also had some time to discuss how they would present their ideas ● Children presented to a member of staff and were able to present the ideas that they had produced across the sessions ● They were able to outline the problem that they had identified and were also able to outline the issues that these caused. They were also able to suggest the solutions that they came up with. They enjoyed the opportunity to present their ideas and used their big picture posters to structure their presentations. Most children spoke confidently and were able to stay on task during the presentations.
WHAT WENT WELL	***IDEAS FOR IMPROVEMENT***
● Children were able to present with some confidence and for the most part were able to stay focused during the presentations. ● This is a big improvement from earlier sessions, as they were able to focus on the specific area they were presenting, rather than speaking about an area that was interesting to them at the time. ● Most children were able to play an active role in presenting their ideas. ● Children enjoyed being given the chance to present their ideas.	● The children could have been given more time to develop and plan their presentations. This would have helped the children stay further on task during their presentations, ensuring they understood the task.

8th session

The 8th and last session was held on 4th July.

<table>
<tr><td colspan="2">Activity: Feedback and Consolidate learning</td></tr>
<tr><td>PLAN</td><td>ACTUAL</td></tr>
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Introduce the systems thinking round table rules (simplified from (SESA 2022))
Topic - “What did you think about the club? Does it help with solving big problems?”
(Only one round) each child will have 1 minute to say something on the topic
Pick-up the cards again and place them in front of them and play the songs roulette.

Here we will have a roulette and each number of the roulette corresponds to a song. After each song the children should raise the Systems Thinking habit card corresponding to the song.
Song list:

MOANA - Know who you are - https://youtu.be/sf3CevfP-E8
ENCANTO - Surface Pressure - https://youtu.be/X-NH1uUfr0U
FROZEN - All is found - https://youtu.be/dpza2z4jmDk
MULAN - I'll make a man out of you - https://youtu.be/TVcLIfSC4OE
THE LORAX - How bad can I be? - https://youtu.be/YYmrPn1CnzY
WALL-E - Let it grow - https://youtu.be/XatUiRnfcNI

Conclusion/Next Steps:

Have a moment to reflect on what was said and close

Resources:

A toy for the person speaking
Wheel with 6 numbers or a big dice.
Systems thinking habit cards.

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Initially in the session, the children had asked if they could have some more time adding to their big pictures. Specifically they wanted to spend some time drawing their solutions to the problem they had identified. Hence this was done instead of the songs activity.
After they had done this we had a discussion about what the children felt they had enjoyed about the club and the Systems Thinking approach.
Children were keen to share that they had enjoyed the opportunities to be given time to share their thoughts and ideas during the Systems Thinking round table time.
They also felt that they enjoyed using the cards
The children also stated that they enjoyed creating their big pictures. This gave the children a chance to be creative

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<tr><td>WHAT WENT WELL</td><td>IDEAS FOR IMPROVEMENT</td></tr>
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• Allowing the children to add to their drawing as part of this session at their request was beneficial. The children enjoyed this as it was something that they had selected to do, but was still beneficial to their overall understanding. • Giving children time to share what they enjoyed form the club allowed them to have a voice and also gave ideas for what could take place/would be important when running a club like this in the future	• Have some open questions to give more frame to guide their feedback

Conclusion

In summary, a cohort of 10 children did an amazing job at learning about systems thinking and applying it to sustainability topics in the span of 8 term time weeks and came up with brilliant ideas around their school. The method for the club was to alternate between a systems thinking round table session and a hands on session. The systems thinking sessions had a little activity to make things interactive and get the children moving at half time. The children really understood the process however, one improvement idea looking back would be to spend more time at the beginning to build their knowledge first on sustainability.

Feedback from the sessions overall:

- Children embraced the systems thinking round table and thoroughly enjoyed it.
- It was an engaging club that children thoroughly enjoyed.
- Children were so engaged that they shared their learning with their parents at home enthusiastically.
- Learning about the approach can help them in their STEM learning.
- It's enriching their curriculum and they can utilize it along with their learning.
- The teacher felt it was beneficial for them to see how we approached this and they can take this forward in other education areas in the school.
- The author believes that based on the feedback the children enjoyed the club and this format can be used in other primary school settings to give children the best start in life with systems thinking.

The author would like to thank the Waters Center (Waters Center 2022) for their support and inspiration for the activities planned for the club.

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Biography

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Harnessing the Power of SySTEAM, Amplified by AI, to Drive Interdisciplinary Pattern Creation and Elevate Engineering Innovation

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Abstract. With the new pervasiveness of AI, pattern recognition is now relatively accessible and easy to incorporate into processes and projects. Large language models (LLMs), transformers, and their ability to recognize patterns across large data sets have become relatively ubiquitous over the past two years. Pattern recognition is a task that AI performs well, but the human ability to combine systems thinking, STEM, and the arts, is extremely valuable in making sense across disciplines and creating interdisciplinary patterns. In other words, for verification and validation of the AI output, human cognition will remain high value-add for any AI pipeline for creative and cross-disciplinary pattern creation. Human cognition will continue to play an important role in creating innovations and taking a holistic, systems thinking approach to problem solving. This will require the collaboration of diverse human skills sets including domain experts (creatives) and prompt engineers (AI manipulators). Educational institutions are encouraged to take a larger look at teaching the foundations of systems thinking, and various aspects of STEAM, so that human cognition can complement AI by having an appreciation for a range of disciplines. Fundamentally, human cognition will be needed on both ends of the creativity spectrum, from ideation to prompt engineering. SySTEAM will play a foundational role in developing transdisciplinary patterns of knowledge to formulate new advancements. Transdisciplinary patterns of knowledge can be shifted from one domain to another to enable breakthrough solutions. One historical example is the Wright Brothers' application of bicycle control principles and technologies toward developing the world's first airplane. Human creativity and AI-enabled pattern development promote adaptability by rapidly ranging across generations, people, and disciplines.

Keywords. Interdisciplinary pattern creation, SySTEAM, pattern recognition, artificial intelligence, small language models (SLMs), large language models (LLMs), cognitive architects

Introduction

ChatGPT was introduced in late 2022 causing artificial intelligence to evolve rapidly due to its simplistic user interface. “ChatGPT gained one million users in just five days after its launch on November 30, 2022. It took ChatGPT only two months to reach 100 million users, achieving this milestone by January 2023” (Hu). Generative Artificial Intelligence (GAI) performs well at recognizing patterns across large data sets known as large language models (LLMs). Even with GAI doing amazingly well at performing pattern recognition, human cognition and experience is invaluable in making sense across disciplines and creating interdisciplinary patterns. The human ability to combine STEM, the arts, systems thinking, history, and cognitive psychology and formulate transdisciplinary solutions ensures that the output of AI is reasonable, non-hallucinatory, and relevant to its human audience. Human cognition adds value in validating the output from AI models. The future of AI is human-centered, with AI serving as an amplifier for human knowledge. Analogous to digital transformation, true success is not about flashy, innovative software applications or LLMs, but about aligning purpose, workflows, and execution across both individuals and technologies. The role of the human in this new paradigm is not obsolete but is more essential than ever. Humans will continue to play an important role in creating innovations and taking a holistic, systems thinking approach to problem solving. Pattern recognition is what AI does. Pattern creation is what humans do. SySTEAM connects the two.

SySTEAM, amplified by AI, is explored in this paper. This framework facilitates pattern creation, not just pattern recognition, enabling the discovery of novel system architectures, behaviors, and human-centered designs. It highlights the convergence of STEAM (science, technology, engineering, arts, and mathematics), systems thinking, AI, cognitive psychology, and historical awareness. This combination presents a framework for maximizing the synergy between human creativity and AI pattern recognition. AI will not replace humans but will augment them. STEAM fosters not only technical fluency but also systems fluency, cultivating an understanding of how human and technical dimensions interact in harmony. With the fusion of AI, humans, and SySTEAM, transdisciplinary patterns of knowledge can be shifted from one domain to another to enable breakthrough solutions. This paper advocates for a framework of interdisciplinary, complementary intelligence that humans and machines collaborate to synthesize patterns across disciplines. Pattern creation across disciplines is the missing link in AI-powered engineering. By combining AI’s brute-force insight with human imagination and systemic awareness, engineers can design systems that are not only efficient but resonant, resilient, and revolutionary. The best AI is not just trained on data; it’s inspired by design, shaped by story, and guided by systems. When combined with AI's pattern recognition and generative capabilities, SySTEAM becomes a force multiplier for interdisciplinary innovation. Pattern creation is the new competitive advantage, and SySTEAM is its catalyst. The future of innovation depends on our ability to not just detect patterns—but to create, reframe, and reinterpret them across disciplines. SySTEAM, amplified by AI, is more than a novel educational approach—it is a strategic methodology and new kind of engineering intelligence for 21st-century innovation.

Current Challenges

There are a set of challenges that exist needing resolution if the integration of AI is going to be successful. “In today’s current landscape, accelerated by the recent inundation of possibilities based on generative Artificial Intelligence (AI), there is frequently the idea that technology alone will solve key problems" (Knaus, Mendenhall, & Simske). "Currently, 70-80% of AI projects fail" (Schmelzer & Walch). The challenges that exist include the following.

- Challenge 1: Experts often work within isolated domains (disciplinary silos) with their own ontologies, methodologies, and goals.
- Challenge 2: AI can recognize patterns but has limitations in contextual understanding.
- Challenge 3: Traditional STEM frameworks tend to favor reductionism and have limitations in contextual understanding.
- Challenge 4: Grants and academics structures frequently favor STEM or arts projects, not hybrids.
- Challenge 5: Managing diverse teams with differing process workflows and mental models is cognitively demanding.
- Challenge 6: The 21st-century engineering challenge isn't complexity alone; it's interconnected complexity across disciplines.
- Challenge 7: AI has become proficient at recognizing patterns in large data sets, but it struggles with novel pattern creation, emotional nuance, and contextual judgment; domains where human imagination and design thinking excel.
- Challenge 8: Difficult to capture-validate SySTEAM outcomes and the return on investment as traditional metrics may not capture the full value of interdisciplinary insights.
- Challenge 9: Today, systems interact in nonlinear, global, and social means. Today's challenges are deeply interdisciplinary, value-laden, and systems-dependent

Implementing SySTEAM for interdisciplinary AI pattern creation is powerful, but complex. AI is strong at pattern recognition using classification, clustering, and trend detection. SySTEAM, on the other hand, is strong at pattern creation, being used to identify emergent relationships, analogies, and cross-disciplinary mappings. Patterns are more than technical solutions; they are cognitive structures for how humans understand and design systems. The convergence of SySTEAM with AI represents a new frontier: machine-augmented creativity in engineering.

Human Intelligence + SySTEAM: The Missing Complement to AI

Human cognitive capabilities remain irreplaceable in engineering design. While AI excels at detecting patterns, humans excel at making sense of them. Humans possess cognitive superpowers that AI does not. Human cognition, especially when informed by systems thinking, historical analogies, emotional intelligence, and psychological insight, brings nuance and foresight that machines cannot replicate. Cognitive psychology reveals how humans recognize analogies, identify heuristics, and mentally simulate scenarios; capabilities that enhance pattern recognition and allow for cross-domain reasoning. History provides innovative case studies for humans to analyze and learn from. One example is when the Wright Brothers applied bicycle control and mechanics to develop human powered, controlled, and sustained flight. Humans offer magnificent value in cross-domain synthesis by using past experiences for connecting ideas from disparate fields. Humans have a unique gift to imagine what solutions could be, not just the as-is current state. Transdisciplinary transfer is not achievable through AI alone. AI becomes most powerful when it stops trying to be human and starts amplifying the best of what makes us human—creativity, empathy, and pattern sense.

Human cognition compared to AI has several advantages. Humans can make cognitive leaps using historical patterns. Meta-algorithmics and meta-analytics combine multiple algorithms to attain better overall system behavior and minimize the severity of errors. Currently, AI lacks the human ability of metacognition and embodied human experience in its training models. AI possesses an absence of analogical thinking frequently, unless the human prompting the model, is telling it to do so. AI is like a microscope that sees details and patterns, but humans are the cognitive architects that integrate patterns into larger systems and solutions. Pattern recognition is useful, and pattern creation is transformative. AI helps detect; SySTEAM helps invent. AI can recognize patterns but only humans can inquire, “Does this pattern matter, and for whom?” The systems engineer of the future is part analyst, part designer, part ethicist—and fully human-centered. In a world of machine intelligence, the systems engineer becomes the pattern conductor. SySTEAM transforms AI from a collection of algorithms into a living system, where creativity, ethics, and context flow through every decision. AI is not the solution, it's the collaborator. SySTEAM engineers build the architecture where that collaboration happens. SySTEAM isn’t just about integrating the arts into STEM; it’s about integrating humanity into technology. This triad of human cognition, SySTEAM principles, and AI amplification-augmentation produces a new form of intelligence for engineering design.

Interdisciplinary Pattern Creation via Ranging Across SySTEAM

SySTEAM extends the boundaries of STEM by incorporating the arts and systems thinking into engineering. Human, AI, and SySTEAM partnerships generate transdisciplinary patterns that fuel innovation. This partnership-framework helps humans translate insights from one discipline to another, creating the potential for breakthrough advancements. Interdisciplinary Pattern Creation is defined as generating patterns, frameworks, or models that draw from multiple disciplines, integrating insights from engineering, art, science, technology, and systems thinking. STEM offers technical foundation, arts provide creativeness, and systems thinking empowers humans to see patterns in complexity and adapt solutions holistically. The “Sy” in SySTEAM can represent both systems and synergy. Embracing SySTEAM combined with AI, individuals become co-creators with AI, rather than passive consumers of AI model outputs. These partnerships generate interdisciplinary patterns that fuel innovation.

Future AI-augmented innovation relies on human roles amplifying AI technologies, and vice versa. This collaborative SySTEAM model creates a dynamic loop where humans provide intent, AI refines outputs, and humans interpret, adapt, validate, and apply AI results with both parties enhancing each other. AI acts as a force multiplier for human creativity when framed together with SySTEAM. The Human AI-augmented construct harnessing SySTEAM will consist of the following roles as a starting point.

- Domain-Discipline Experts (Creatives): Bring deep contextual knowledge that grounds AI-generated insights

- Prompt Engineers (AI Manipulators): Guide and shape AI behavior through effective input design
- Creative Generalists: Bridge the gap between disciplines, often initiating the kind of pattern creation AI struggles to achieve
- Data Scientists: Refines the AI's pattern recognition to detect subtle correlations
- Cognitive Architects: Apply psychological understanding to human-AI collaboration design
- Historically Literate Innovators: Use analogical reasoning and historical awareness to identify translatable patterns from the past

Ultimately, the convergence of human cognition, AI technologies, and SySTEAM results in amplified intelligence and innovative, interdisciplinary solutions. STEAM cultivates diverse perspectives critical for innovation. Artificial intelligence without systems thinking is powerful but somewhat blind. SySTEAM gives AI vision that is rooted in empathy, context, and creativity. SySTEAM provides the feedback loop that prevents AI from becoming technocentric or biased. Systems thinking, ethics, and creative reflection keep AI grounded and responsive to the real-world system it supports. Just as an operational amplifier strengthens faint electrical signals to drive meaningful output, AI within a SySTEAM framework, amplifies the subtle nuances of human creativity, empathy, and system context—producing engineering solutions that are not only powerful, but profoundly human-centered.

Educational Evolution to Harness the Convergence of Humans, AI, and SySTEAM

Within the educational construct, traditional discipline majors should be improved to broaden areas of study and expertise prior to graduation. One way to achieve this is if a student majors in a STEM discipline, they should minor in the arts, or vice versa. Educational institutions should teach systems thinking as a core literacy. They need to start the immediate shift to equip students with AI training and to include prompt training and use. Systems thinking helps AI understand complexity and interconnections. Integrating cognitive psychology principles into STEAM disciplines would be impactful to strengthen reasoning. Academic institutions should shift back to integrating history and add historical case-study based learning to strengthen analogical reasoning and insight. Additionally, academic environments need established to encourage collaborative, multi-disciplinary learning. Curricula need to transform to foster interdisciplinary fluency and celebrate being a generalist across subjects, versus a specialist in a single discipline. SySTEAM should be embedded across education and design workflows. Innovative models such as Co-Pattern Development Studios, could serve as incubators for this type of thinking. Academic institutions should prioritize preparing students to complement AI, by using AI to amplify human cognition, versus reliance on outsourcing cognitive tasks. Furthermore, schools and colleges must encourage students to explore complex systems using both analytical and creative tools. "Creativity is now as important in education as literacy, and we should treat it with the same status" (Robinson). SySTEAM is not merely additive but integrative. It equips engineers to see the big picture and the fine details simultaneously, enabling deeper insight into not only how systems function, but how they are experienced. The digital world around us is rapidly evolving and injecting innovation into the educational ecosystem to keep up is paramount.

Applied SySTEAM, AI, and Human Collaboration: Case-Based Pattern Creation

The case study explored here is next generation, sustainable passenger aircraft design. This case study demonstrates how humans, AI, STEM, and the arts can collaborate in an interdisciplinary framework. Combining GAI + small language models + large language models + simulation learning. Designing a next-generation, sustainable passenger aircraft that includes the following.

- The Arts: Cognitive psychology, aesthetics, and architectural principles
- STEM Specialties: materials science, data science, fluid dynamics, and propulsion
- Systems Engineering and Systems Thinking: Serves as a foundation for interdisciplinary integration
- AI: Enabling pattern recognition, generative design, and interdisciplinary design synthesis

This case study ties together SySTEAM and human-AI teaming for advanced engineering design and illustrates how AI can support pattern creation and innovation across multiple engineering domains. Interdisciplinary transfer learning involves taking lessons from the arts and feeding back into core STEM disciplines and below are examples of the SySTEAM-human-AI triad.

AI + Fluid Dynamics (STEM):

- Inputs: Computational fluid dynamics (CFD) data, historical aircraft geometries, biological structures
- AI teaming:
    - Use generative designs models to evaluate and create new airframe contours
    - Small Language Models (SLMs) fine-tuned with domain-specific literature support design annotation
- Outputs: Novel, blended wing body with micro-ripple skin pattern enhances turbulence control, inspired by biomimicry
- Engineering Intelligence Insight: AI becomes a co-designer that amplifies nature-derived aerodynamic innovation

AI + Aesthetic Airframe Design (using the STEM and Arts):

- Inputs: Historical aircraft designs, user sentiment data, and aesthetic ratios (e.g. golden ratio aesthetics for aircraft architecture)
- AI teaming:

    - Use LLMs to correlate user feedback with aircraft appearance and human interface preference
    - Use generative adversarial networks (GANs) to converge aesthetic design harmony with functional aircraft shapes

- Outputs: A symmetric swirl fuselage that balances airflow, reduces drag, and enhances visual appeal
- Engineering Intelligence Insight: Aesthetic and aerodynamic performance converge through iterative AI-human design loops

AI + Propulsion (STEM + Green energy alternatives):

- Inputs: Noise profiles, environmental impact data, fuel burn rates, thermodynamic engine performance profiles
- AI teaming:
    - Design patterns merge traditional jet turbine maps with noise reducing, ionic propulsion concepts
    - Make use of graph neural networks to model novel, hybrid engine cycles
- Outputs: Dual-engine propulsion design with variable bypass ratios optimized for different flight phases
- Engineering Intelligence Insight: AI supports the creation of quieter, cleaner propulsion architectures aligned with environmental goals

AI + Materials Science (STEM + Nature + GAI Design):

- Inputs: Materials fatigue – stress data, biological structure patterns
- AI teaming:
    - SLMs and LLMs trained on biomimicry datasets
    - Stable diffusion models can enhance concept sketch-to-CAD workflows by automating the generation of detailed isometric drawings from textual descriptions, which are then transformed into precise CAD models
- Outputs: Nature-inspired materials and structures rapidly prototyped through AI-enhanced workflow
- Engineering Intelligence Insight: AI accelerates the journey from conceptual inspiration to manufacturable design

AI + Flight Deck Design (STEM + Arts + Psychology):

- Inputs: Historical control layouts, design aesthetics, user experience (UX), human factors research, and pilot interviews
- AI teaming:
  - Multimodal generative models synthesize text, sketches, and 3D feedback into adaptive flight deck interfaces
- Outputs: Flight deck display pattern modeled as a balance of art, human interaction, science, systems thinking and optimized for cognition, safety, and aesthetics
- Engineering Intelligence Insight: SySTEAM ensures that human factors, UX, and aesthetics are integrated into the flight deck experience

SySTEAM empowers AI with empathy and imagination, enabling machines to partner with humans rather than replace them. AI-driven pattern creation transforms design from siloed optimization to holistic co-creation. By embedding systems thinking and the arts into AI workflows, we unlock a deeper form of intelligence, one that understands not only data but also human meaning and context. This approach reframes AI not as automation, but as augmentation—enhancing human creativity, insight, and innovation.

If AI only uses STEM versus SySTEAM

GAI has a centrist mentality since its approaches to creativity are based on the averaging effect of training data. In relation to the aircraft case study mentioned previously, STEM-centric AI results in the following characteristics. Aircraft design using STEM-centric AI would optimize for forces of flight and lack biomimicry, resulting in a standard evolutionary design. User interfaces may ignore the human aspect in which flight decks are not designed for cognition and lack advanced human systems integration. Relying on STEM-centric AI may result in a lack of aesthetic appeal and passengers may not marvel at the interior or exterior design of the aircraft. The STEM-centric design using AI may miss cultural and historical contexts and tend to ignore historical patterns, psychological biases-effects, and cultural values. SySTEAM is where disciplines converge and creativity thrives, unlock AI's full potential to design systems that serve, inspire, and endure. Without emphasis on SySTEAM, STEM-centric AI will likely lack aesthetics, empathy, biomimicry, psychology, social, and ethical contexts. Without SySTEAM, AI risks becoming a black box; with SySTEAM, AI becomes a transparent, adaptable collaborator. In the age of AI, artists are not optional; they are architects of meaning, ethics, and emotional intelligence. The real magic happens at the intersection of disciplines. Steve Jobs once quoted, "Technology alone is not enough. It's technology married with the liberal arts, married with the humanities, that yields us the results that make our hearts sing" (Riggs).

Conclusion: The Future of AI through the Lens of SySTEAM; A Human-Centered, Interdisciplinary Approach

The future of artificial intelligence depends not solely on advanced algorithms or vast datasets, but on the thoughtful integration of SySTEAM, where systems thinking intersects with science, technology, engineering, arts, mathematics, and artificial intelligence. This fusion of disciplines enables a new era of human-AI-SySTEAM teaming, where pattern recognition evolves into pattern creation unlocking entirely new design spaces that are more creative, intuitive, and human-centered.

Blending AI and core STEM fields (such as aerodynamics and materials science) with the arts (including aesthetics, ethics, philosophy, and psychology) empowers engineering to transcend optimization and embrace beauty, empathy, and purpose. With SySTEAM, design becomes both rigorous and expressive. For example, in aircraft development, we see the emergence of aerodynamic forms with golden-ratio grace, where efficiency and elegance co-exist by design.

In this paradigm, AI becomes a co-designer, a pattern collaborator in an ecosystem composed of human expertise, systems thinking, computational power, and artistic intuition. This synergistic triad of human cognition, SySTEAM, and AI advances engineering design intelligence that is more integrated, ethical, and adaptive. It ensures AI does not just detect patterns in data but begins to understand the meaning behind them, becoming a true partner in innovation rather than a mere tool. The future belongs to those who can connect creativity with computation, and empathy with algorithms.

SySTEAM breaks down disciplinary silos and unites diverse perspectives to address complex challenges with holistic insight and imaginative solutions. It ensures AI is transparent, trustworthy, and designed to augment human potential rather than replace it. AI agents, when guided by SySTEAM principles, simulate, iterate, and evolve design patterns rapidly, enabling cross-disciplinary experimentation at unprecedented speed and scale.

For systems engineers, SySTEAM is where disciplines converge, and creativity thrives. AI enables this creativity by recognizing patterns in biology, psychology, philosophy and art, and then reapplying them in engineering. SySTEAM provides more than an educational framework; it offers a strategic blueprint for creating AI that integrates across domains, anticipates unintended consequences, and enhances human purpose. As Maurice Conti aptly stated, “The fusion of art and science is the only way to ensure that AI mirrors the richness of human experience.”

SySTEAM bridges the gap between technology and humanity. It drives AI innovation that is ethical, empathetic, and effective. As AI becomes increasingly embedded in socio-technical systems, SySTEAM ensures that solutions are not only technically sound but also ethically grounded, user-centered, and context-aware. It brings together the precision of engineering, the creativity of the arts, and the breadth of systems thinking, enabling engineers to architect intelligent systems that can adapt, collaborate, and learn within complex environments.

SySTEAM encourages collaboration across multiple disciplines to solve the complex, nonlinear challenges of today. For INCOSE practitioners, SySTEAM isn’t just an educational ideal; it’s a strategic imperative and blueprint for creating AI that is as humane as it is powerful, where technology respects complexity, fosters collaboration, and elevates the human experience. We need wiser engineers, broader systems, and tools that help us see what truly matters. Elevating engineering innovation is the promised result for human engineers harnessing the power of SySTEAM, amplified by AI.

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Biography

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Can Employability Skills be Developed and Measured? The Helix Employability Skills Measurement Framework

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The Helix Employability Skills Framework

There are three essential and inter-related sets of skills that are acquired by the most valued and effective individuals as they develop through personal and organizational experience and purposeful change. These are (1**) self-leadership and learning**, (2) **team leadership and collaboration,** and (3) **complex problem solving** (McDermott, Hutchison, and Crick, 2021). These are supported by a set of foundational and domain-centered skills. Employability skills are interdependent and develop iteratively through practice in authentic work-related contexts. They are at the heart of the Helix study which was conducted by the Systems Engineering Research Center to discover the sets of proficiencies that make a systems engineer effective in their roles (Hutchison et al. 2018). Each of these three skillsets is supported by tools of different types and can be embedded into education and organizational learning programs and each is measurable using an integrated set of competency-based assessments. One can map out a set of competencies and related proficiencies to frame learning objectives in a project-based learning environment. The Helix Employability Skills (HELIX^{EMP}) assessment framework was developed as an integrated measurement toolset to assess development of these skills over time.

Employability Skills

Employers continuously talk about the "need for better critical thinking skills" or "employees who have already mastered the soft skills" or "better problem solving" or even just the need for "more adaptable and flexible" employees. No matter what career, or job, or even activity that has been your focus for the past several years, you probably have experienced a lot of change. The situation that employers are responding to is "rapidly changing internal and external conditions." Employers need people that develop a life-long ability to quickly learn new skills that help them adapt to rapidly changing internal and external conditions. Employees who have these abilities can be characterized by their well-developed employability skills.

Employability skills are defined as the general skills that are necessary for success in the labor market at all employment levels and in all sectors and easily transfer from job to job. (Nisha and Rajasekaran, 2018) They may be referred to as “soft”, “workforce readiness”, “career readiness”, or “21st century” skills.

There are a number of studies defining employability skills. The Office of Career, Technical, and Adult Education (CTE) of the U.S. Department of Education recently published a framework for education of employability skills. Table 1 identifies the primary components of each of these skills from the CTE framework.

Table 1. Employability Skills and Primary Skill Components (https://cte.ed.gov/initiatives/employability-skills-framework).

Employability Skill	Skill Components
Systems Thinking	Understands systems, uses systems principles, collaborates in teams, assesses progress, evolves and adapts solutions
Critical Thinking	Thinks critically, thinks creatively, reasons about problems and solutions, makes sound decisions, solves problems, plans and organizes approaches to solve problems
Communication	Communicates verbally, listens actively and responds appropriately, observes carefully, comprehends written material, conveys information in writing and visually
Applied Academics	Effective applies reading, writing, math strategies, and scientific method to work strategies
Resource Management	Manages time, manages money, manages personnel, manages other resources
Information Use	Locates data and information, organizes data and information, uses data and information, analyzes data and information, communicates relevant information to others
Technology Use	Understands technology, uses different types of technology, recognizes how technology can be employed to solve problems
Interpersonal Skills	Understands teamwork and works with others, shows leadership, negotiates, respects individual differences, responds to others' needs
Personal Qualities	Accepts responsibility, exhibits self-discipline, takes initiative, works and learns independently, shows willingness to learn, adaptive and flexible, demonstrates professionalism, positive attitude, sense of self-worth, takes responsibility for professional growth

Table 1 includes both learned skills and developed personal characteristics or dispositions that allows individuals to use each skill effectively. Highly effective employees develop all of these skills and characteristics (dispositions) in their careers.

The Helix Study

The Helix project completed a multi-year research study targeted at identifying the proficiencies of effective systems engineers. Helix interviewed hundreds of successful systems engineers in various career stages to derive a model for these proficiencies and personal and organizational characteristics that enable them. Helix additionally worked with organizations to find the organizational characteristics that enable development and proficiency in systems engineering (Hutchison et al. 2018). The Helix project developed a proficiency assessment toolset (https://helix-se.org), that was able to assess and track these proficiencies across a career using self- and peer- assessments. Helix also created an organizational assessment toolset that measured organizational support for systems engineering and the cultural aspects that encouraged effective systems skills.

Generalizing the Helix Framework to Employability Skills

Our research found that Helix, when generalized to non-systems engineering roles, provides an integration framework for the development and assessment of employability skills. There is a strong correlation between the systems engineering skills of Figures 1 and 2 (below) and the employability skills of Table 1. Systems engineering was created as a discipline for managing complex systems and projects across collaborating teams of people. Effective systems engineers exhibit advanced complex problem-solving, self-leadership, and team collaboration skills. Employers desire above all else people who have these skills and can adapt and grow in a complex and adaptive world.

Helix found six proficiency areas and personal characteristics that now form the heart of the global employability skills frameworks. The resulting combined framework is shown in Figure 1 (below). One might view the development of any early professional career as a progression of proficiencies from **foundational learning** to **experience in domain** to expansion into broader **systems responsibilities and disciplines**. These are domain and disciplinary proficiencies typically developed in educational programs and applied to our jobs. Further development extends to the individual characteristics and skills developed with experience and learning on the job that support **complex problem solving**, **self-leadership and learning**, and **team leadership and collaboration**. These are the employability skills that are so desired and are often learned on the job. They should also be developed in educational programs but with a focus on lifelong learning. Organizational forces such as mentoring, on-the job training and experience, and a supportive environment for learning will affect the attainment of employability skills.

The impact of the Helix framework depends on how it is applied in an organizational learning environment to develop and assess the desired individual proficiencies. Each of the proficiencies listed in Figure 1 should be intentionally developed and assessed at the institutional level, in both education and business contexts.

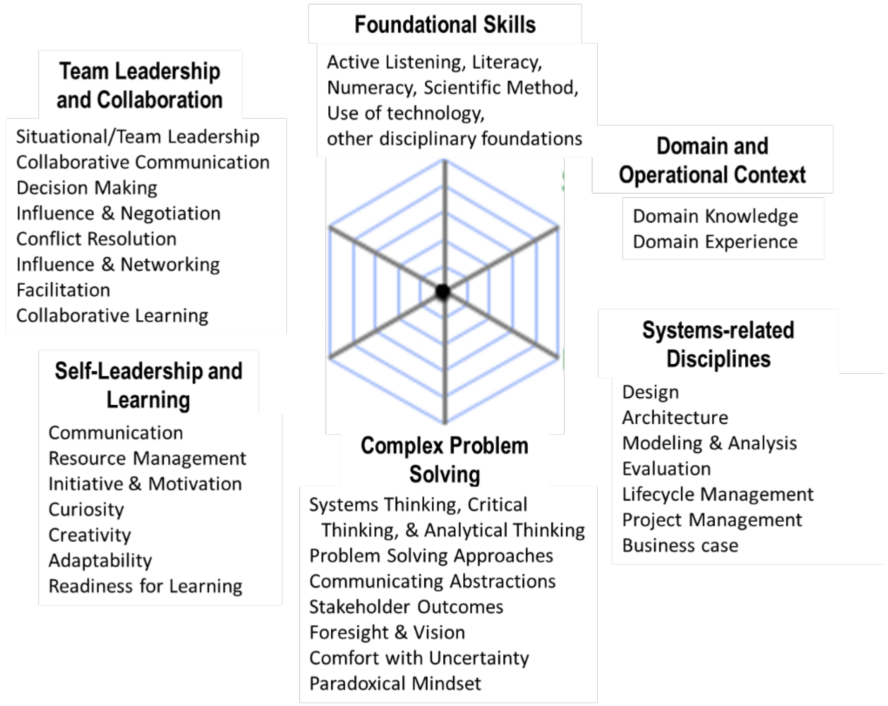

Figure 1. Helix framework extended to employability skills.

Why Employability Skills Assessment is Important

The generalized Helix model correlates strongly with widely published data on employer desired skills. Figure 2 is the World Economic Forum's list of top-10 most desired employer work skills over the last 15 years, as organized by the employability skills proficiency areas (color codes).

World Economic Forum Top 10 Skills Survey Results

Most In-Demand Skills of 2015	Most In-Demand Skills of 2020	Most In-Demand Skills of 2025
1. Complex Problem Solving	**1. Complex Problem Solving**	1. Analytical Thinking & Innovation
2. Coordination with Others	**2. Critical Thinking**	***2. Active Learning/Learning Strategies***
3. People Management	**3. Creativity**	***3. Complex Problem Solving***
4. Critical Thinking	4. People Management	**4. Critical Thinking & Analysis**
5. Negotiation	5. Coordination with Others	**5. Creativity, Originality & Initiative**
6. Quality Control	6. Emotional Intelligence	6. Leadership & Social Influence
7. Service Orientation	7. Judgment & Decision Making	7. Technology Use, Monitoring & Control
8. Judgment & Decision Making	8. Service Orientation	8. Technology Design & Prototyping
9. Active Listening	9. Negotiation	9. Resilience, Stress tolerance, Flexibility
10. Creativity	10. Cognitive Flexibility	10. Reasoning, Problem-solving, Ideation

Figure 2. World Economic Forum most In-Demand Skills Rankings.

The World Economic Forum (WEF) Future of Jobs reports survey global human resources and strategy experts a step to understanding shifting employer needs over time (WEF 2016, WEF 2020). Although the lists change over time, the themes remain really clear.

Adaptive Learning/Learning Strategies and **Complex Problem Solving** are highlighted in Figure 4 as these are the core aspects Systems and Critical Thinking. Many systems engineers will tell you that being a "lifelong learner" is a core characteristic of effective systems engineers, but most competency models ignore "readiness for learning" as a defined skillset. Systems thinking approaches often define core aspects of their effectiveness as "learning by solving problems." A primary result of viewing employability skills through the lens of assessment, not just competencies, is the focus on learning to effectively do the skills so desired by employers. Employers want their people to be proficient at doing, not just trained in a skill. The adaptive learning/complex problem solving capability areas are further defined as:

- **Complex Problem Solving**: not just solving problems, but using a collection of processes and activities related to the cognitive, emotional, and motivational aspects of ourselves, applied to dynamic situations, to achieve ill-defined goals (Dorner and Funke, 2017). This means that learning to solve problems in complexity must be relevant to all aspects of ourselves as related to the system we are working on and living in.
- **Self-Leadership and Learning**: capabilities associated with a person's motivation, adaptation, and readiness for learning. Many organizations call this "taking initiative" in their employee assessments but it is much more complex than that. It is how people respond to risk, uncertainty, and challenge and also their ability to purposefully 'learn their way forwards' to design, engage, fail, learn, and generate new knowledge which improves or transforms the job to be done. (McDermott, Hutchison, and Crick, 2021)
- **Team Leadership and Collaboration**: capabilities associated with individual and group collaborative learning capacity as it is manifested in relationships between people who are aligned around achieving a shared purpose of value. This is about collaborating in teams to identify problems, conceptualize broad responses, and compose successful new solutions which add value for the stakeholders. It is about the ability to conceptualize (model), plan for, and successfully implement transformative change. (McDermott, Hutchison, and Crick, 2021)

The HELIX^{EMP} Assessment Framework

The original HELIX^{SE} Systems Engineering Effectiveness framework was incorporated into an assessment tool that allowed individuals to self-assess their current proficiency levels in each of the Helix categories and track their development over their careers. The HELIX^{EMP} assessment framework is a completely new toolset designed to evaluate development of employability skills over an individual career. While domain skills will change with new roles and domains, employability skills should show consistent development and attainment across roles and domains. The current HELIX^{EMP} assessment tool consists of four surveys: Employability Skills Foundations, Self-Leadership & Learning, Team Leadership & Collaboration, and Complex Problem Solving. The surveys are currently available at no-cost and can be taken at https://emp.helix-se.org/. Figure 3 depicts the analysis results available after taking each of the four individual surveys.

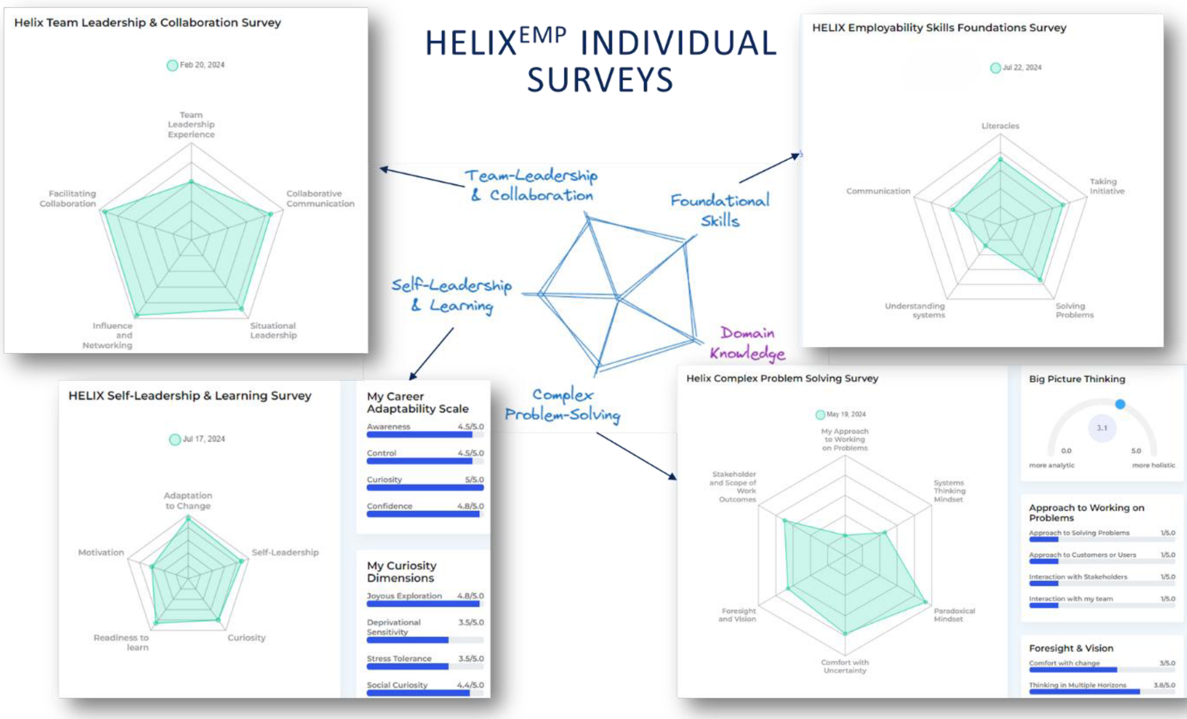

Figure 3. HELIX^{EMP} Individual Surveys.

In addition, each survey has a link to educational materials that explain the individuals survey results and how to improve each set of employability skills. An example is shown in Figure 4.

The surveys are currently being validated with hundreds of students in the Defense Civilian Training Corps (DCTC) educational program, using the HELIX^{EMP} framework to define the leadership and systems thinking education content of that program. Opportunities with organizations are being sought to further validate the framework.

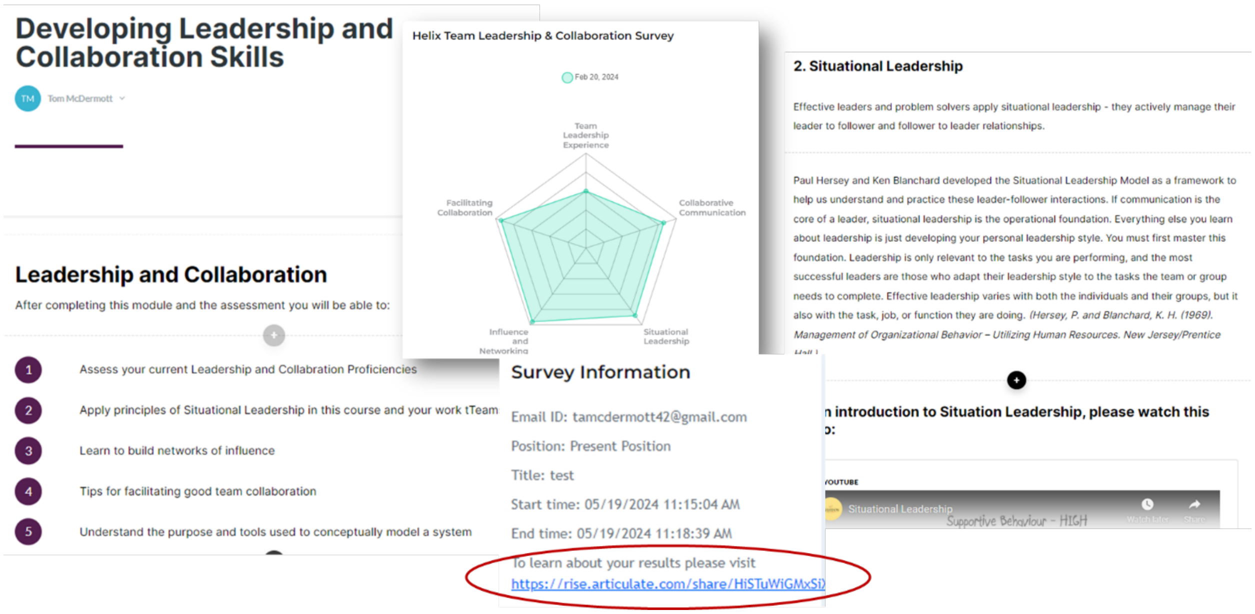

Figure 4. Example HELIX^{EMP} Learning Content.

Helix in Organizations

The organization influences the forces that build complex problem-solving proficiency through not just roles, but also enabling organizational characteristics and organizational development initiatives. These are shown in Figure 5. The Helix study also characterized the forces that affect the development of effective problem solving proficiencies in organizations.

A "complex problem solver" fills a position in their organization which is probably not titled or even focused on that aspect of their work. Attainment of roles often defines our focus at work and an individual's personal development initiatives are often linked to their role. However, "complex problem solver" and "learner" and "systems and critical thinker" are not defined roles and probably will never be. Employability skills are by definition transferrable from role to role. The challenge is to help people develop the necessary skills broadly across an organization independent of role. Employability skills are often still not a focus of employee development. Specifically creating educational programs to advance "employability skills" may serve as an antidote to the primarily disciplinary learning that starts in educational institutions and tends to carry forward into business, as the concept of employability skills is easily understood by organizations and their human resource departments.

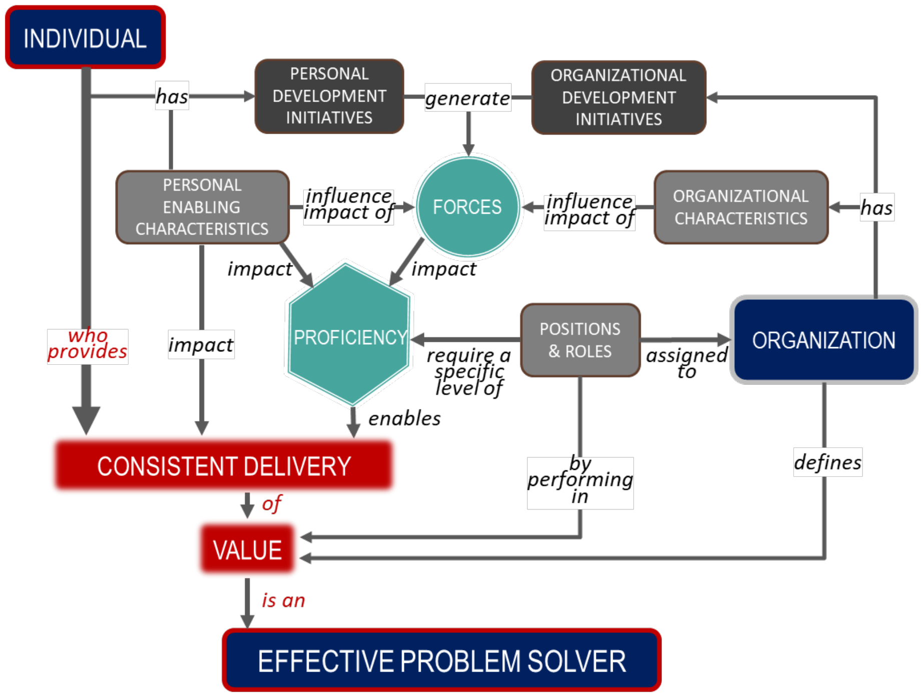

Figure 5. Organizational and personal "forces" build complex problem solving skills.

A critical organizational force is the collaborative learning that comes from working in teams. The organization must support periods of reflection within team oriented projects where the complexity of the situation can be reanalyzed, and solutions visualized. These serve as opportunities to view problems in complexity and for practicing adaptive learning. In the pace of today's business activities, it is easy for organizations to unintentionally create forces that inhibit development of employability skills. Organizational leadership must establish and incentivize a collaborative environment; establish effective environments and times where individuals can share knowledge and create shared learning; support within these data-driven activities that promote systems and critical thinking, use of information, use of technologies; and use these to promote and coach individual communication skills (McDermott 2019). In these team-based and outcome-driven activities, people can improve their personal qualities and interpersonal skills through these more open-ended team activities. In summary, give a team of employees an open ended problem related to the organizations domain, and use it as an opportunity to train and coach these types of employability skills (not just domain skills).

Organizations and educational institutions must create the environment to learn and use these employability skills. Helix used of the Quality of Interaction (Qi) Framework as one component of an assessment tool for organizations, measuring cognitive diversity and psychological safety (Qi). Teams solve problems faster when they are more cognitively diverse, and team members are more generative and adaptive in an environment of psychological safety (Reynolds and Lewis 2018). Formal education and development of experience in the systems and critical thinking processes, methods, and tools are critical to learning or "generative" organizations

(Senge 1990) and to organizational needs for greater adaptiveness, which might be described as architectural attributes. "Leader as architect" has long been described as core to organizational success (Collins 2001).

Applying employability skills while collaborating in teams is the force for skill development. Assessment of employability skills at the beginning and end of a team project aids in isolating the improvement areas and support of developmental learning. Teams must be able to develop a mindset and processes to be creative and to visualize and communicate knowledge in complex situations. The organization must support periods of reflection within projects where the complexity of the situation can be reanalyzed, and solutions visualized (McDermott 2019). In the pace of today's business activities, it is easy for organizations to unintentionally create forces that inhibit development of employability skills. Organizational leadership must establish and incentivize a collaborative environment, support data collection and analysis activities that support situational understanding of both internal and external context, establish effective environments and times where individual can share knowledge and create shared learning, and promote creative narrative and storytelling along with analytical data (ICCPM 2012; McDermott 2019). What remains missing from most competency guidance is "create shared learning" and the assessment models that focus in on these skills and dispositions. Individuals and organizations can learn from the systems engineering community how to develop people with the employability skills desired today.

The current HELIX^{SE} toolset includes an organizational assessment capability that focuses on individual and peer evaluation of skill development forces along with an organization's culture for adaptive learning. The HELIX^{EMP} organizational assessment toolset is currently in development.

Helix in Formal Education

The HELIX^{EMP} toolset was first integrated into a master's level postgraduate course on Systems and Critical Thinking in a technical leadership program at Agnes Scott College in Atlanta Georgia. This course was first taught in 2019 and the HELIX^{EMP} surveys were initially integrated in 2022. In 2024 the surveys were integrated into the current tool and introduced into a fourth year undergraduate 2-semester course in the Defense Civilian Training Corps (DCTC) program. The DCTC partnership between the Department of Defense (DoD) and academia represents a first-of-its-kind investment to prepare and ensure the readiness of college graduates to become new civilian acquisition professionals (see dctc.mil). DCTC goes beyond scholarship-for-service to include curricula, immersive learning experiences on campus, project-based summer internships at DoD installations, and experiences that instill resilience and critical DoD skills on top of students' major field courses. This integrated approach was tailored to align with the critical skills needed for the workforce of the future, providing scholars with a head start in cultivating the network, community, and support needed for personal and professional success.

The DCTC critical skills are shown in Figure 6.

Figure 6. DCTC Critical Skills include both domain and employability skills.

These skills are exercised in a project-based learning program. The students participate in a summer internship with a government sponsor, then return for their fourth year into a 2-semester course that allows them to continue working on a relevant DoD project with a DoD sponsor. Projects are selected to emphasize DoD System and Digital and Data Skills. Employability skills are exercised through a combination of critical thinking, systems thinking, design thinking, and innovation and entrepreneurship tools.

The four HELIX^{EMP} surveys (Foundations, Individual Self-Leadership and Learning, Team Leadership and Collaboration, and Complex Problem Solving) are integrated into the curriculum at various stages as follows:

1. **Employability Skills Foundations** are assessed early in the curriculum and used to have the students self-assess and reflect on core skills related to literacies, personal initiative, communications, and understanding of systems. As "understanding systems" is a poorly exercised skill in many of the students, early learning in the curriculum focuses on defining their project in the context of the larger DoD system it would be deployed into. The students evolve their project in 2-week sprints that emphasize effective communication.
2. **Team-Leadership and Collaboration** is a learning focus in the first semester. These are team-based projects, and the curriculum teaches the core skills necessary to work in and lead teams, noting that team leadership is situational. These skills include the role of the leader and follower, the practices and abilities of strong team leaders, and the character of leadership.
3. **Self-Leadership and Learning** is integrated with team leadership in learnings about the characteristics of exceptional leaders such as emotional intelligence and trust. Figure 7

shows how team leadership and self-leadership are measured in HELIX^{EMP} with respect to learned behaviors in the leadership curriculum.

4. **Complex Problem Solving** is assessed in the “problem solving” aspects of the project-based exercises as the students integrate their proposed solution with their broader understanding of the DoD organizations that will use it. This aspect of the curriculum is strongly focused on visual systems thinking tools

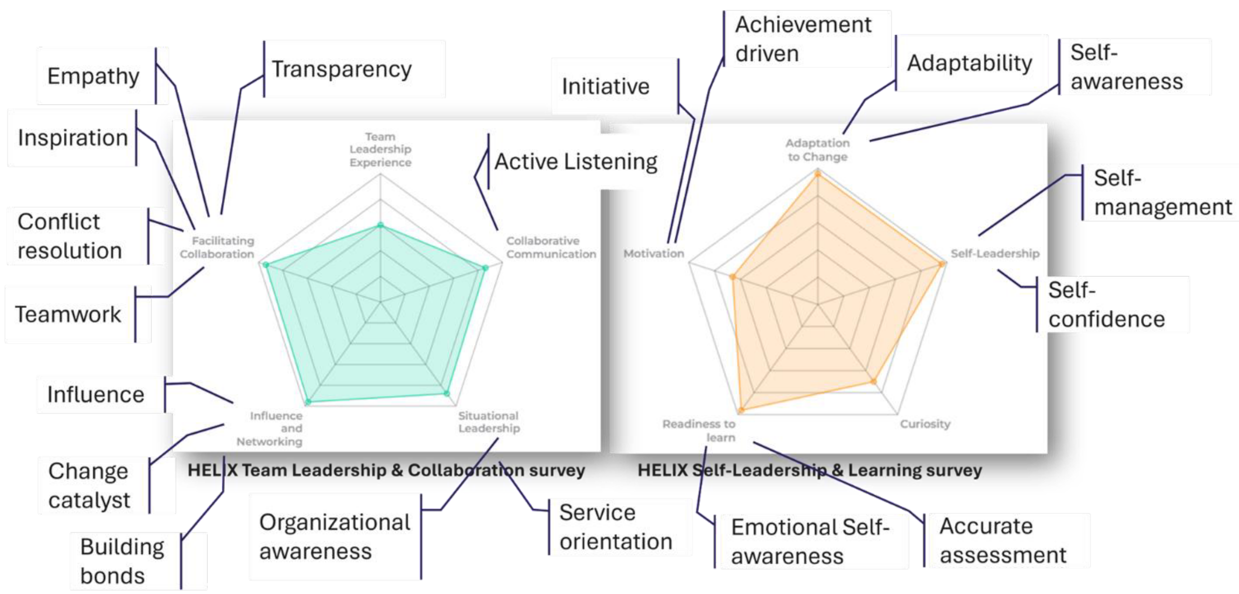

Figure 7. Core skills of the HELIX^{EMP} Team Leadership and Self-Leadership surveys as assessed in relation to the leadership curriculum.

Application and Conclusion

Many employers desire workers with the self-leadership, team leadership & collaboration, and complex problem solving skills that are coming to be known as employability skills. According to the HELIX study, effective systems engineers have well-developed employability skills. The extended Helix study discussed in this article found that effective systems engineers naturally develop employability skills over time, and that these can be assessed in individuals and organizations in any discipline or domain. However, institutions must create the environment and structure the learning to focus on and accelerate development of these skills.

The HELIX^{EMP} survey tool and the DCTC education program are perhaps the first attempt to fully integrate measurement of these skills and a curriculum to attain these skills into an undergraduate university education program. To date over 90 students across four universities have taken the surveys and completed the education program. The full effectiveness of the program cannot be measured until the students have reassessed their HELIX^{EMP} skills after 1-2 years in the workforce. Initial qualitative assessments indicate the HELIX^{EMP} framework is an effective means to structure learning content in an undergraduate educational program in institutions of higher learning. The DCTC program will expand in the future to additional universities and the HELIX[EMP] survey tools open up the opportunity for extensive study of employability skills development over time.

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HELIX Employability Skills

HELIX has been expanded into a more **generalized** proficiency framework **individual effectiveness**, combining insights from Helix^{SE}, additional competency frameworks (INCOSE, Complex System Development, SFIA, etc.).

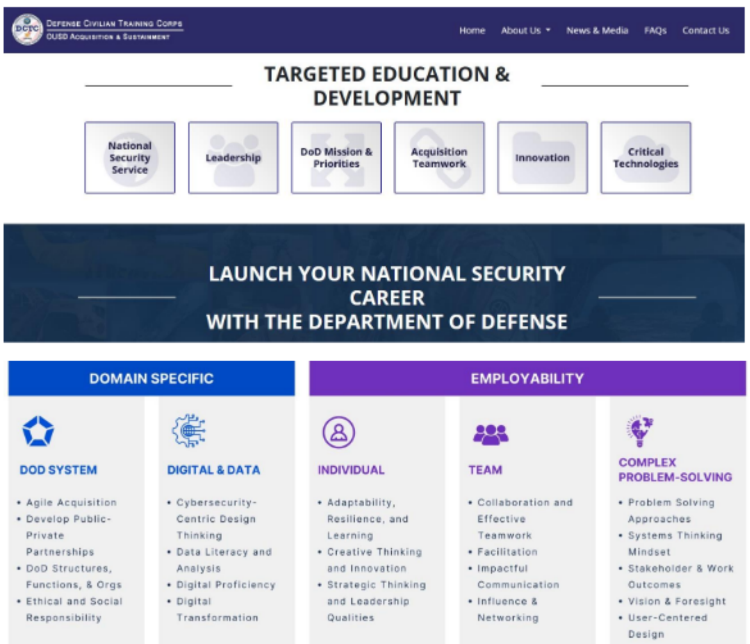
HELIX Employability Skills (Helix^{EMP}) enables individuals to understand their capabilities in terms of self-leadership and learning, team leadership and collaboration, and complex problem-solving as well as their foundational employability skills.

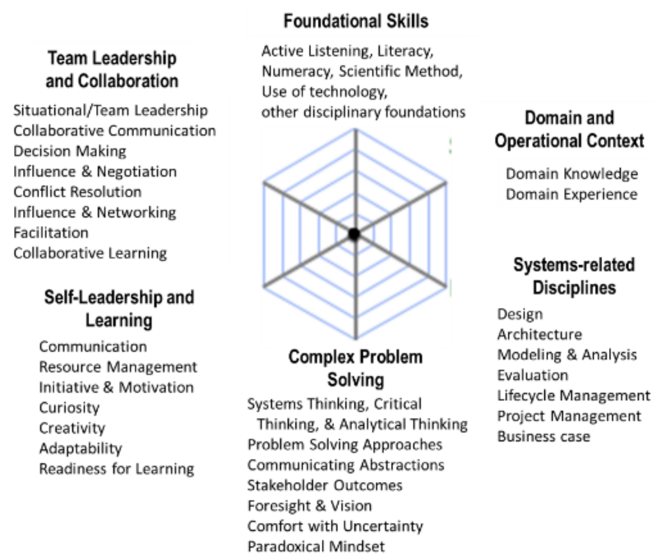
Employability skills are applicable across a diverse set of disciplines and domains.

https://emp.helix-se.org/

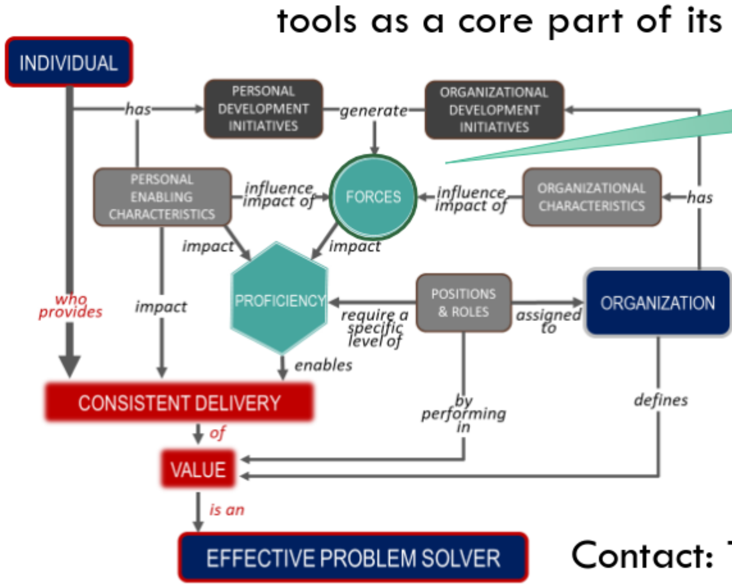
Take our Surveys

Defense Civilian Training Corps (DCTC)





DCTC uses the HELIXEMP framework and self-assessment tools as a core part of its learning experience



How to create these forces in undergraduate education?

- Individual & organizational **forces** create the environment for active learning and complex problem solving
- Supported by individual incentives & organizational opportunities
- Producing value to the individual & organization

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Modeling Beyond the V: Using Model-Based Systems Engineering (MBSE) and STEAM Goals to Unlock Creativity in Systems Engineering Education

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Abstract

Traditional systems engineering education often emphasizes structured processes and technical formalism, reinforcing a narrow focus on compliance and documentation. While effective for instilling analytical discipline, this approach can limit opportunities for creativity, innovation, and broader stakeholder engagement —capabilities that are increasingly critical in today's complex, interdisciplinary design environments. This work proposes a pedagogical shift: leveraging Model-Based Systems Engineering (MBSE) as a rigorous modeling methodology and a platform for integrating creativity and human-centered thinking consistent with STEAM education goals. Drawing on systems engineering and design thinking principles, this work outlines concrete strategies for using SysML and MBSE frameworks to support conceptual exploration in the classroom. Students are guided to model alternative architectures, explore system behavior iteratively, and embed non-functional requirements, including social, ethical, and aesthetic considerations, within the system model. Specific instructional techniques include stakeholder-centered modeling using use case and requirements diagrams, function exploration through activity and block definition diagrams, and scenario-based system validation. By embedding STEAM values into MBSE workflows, educators can reinforce traditional systems competencies, such as requirements engineering, interface modeling, and lifecycle planning, while fostering innovation, empathy, and integrative thinking. This blended approach helps students become more well-rounded systems engineers: technically proficient, creatively agile, and prepared to address the multifaceted challenges of modern socio-technical systems.

INTRODUCTION

Systems Engineering Education

Systems engineering instruction has long followed the V-model to train students in system definition, design, and validation (Forsberg, Mooz, & Cotterman, 2005). Originating in defense and aerospace, this approach emphasizes traceability, documentation, and adherence to fixed requirements (Pyster et al., 2012). While effective for instilling rigor and analytical structure, it tends to limit flexibility, stakeholder engagement, and attention to non-technical factors (Sheard & Mosterman, 2009). As systems become increasingly interconnected and socio-technical, engineers must be prepared to navigate uncertainty, account for ethical trade-offs, and operate across disciplinary boundaries (Hess & Fore, 2018).

MBSE

According to the International Council on Systems Engineering (INCOSE), Model-Based Systems Engineering (MBSE) is "the formalized application of modeling to support system requirements, design, analysis, verification, and validation activities beginning in the conceptual design phase and continuing throughout development and later lifecycle phases" (INCOSE, 2007). MBSE replaces traditional document-centric approaches with digital models, often expressed in SysML, that serve as the authoritative source of system data. These models represent the system's structure, behavior, interfaces, and constraints in a consistent and traceable form, and are interpretable by both humans and machines.

A systems model constructed using MBSE methods resides in a shared repository and can be queried, reused, and analyzed throughout the system lifecycle. MBSE enables early architecture visualization, impact analysis, and iterative evaluation of design alternatives. Changes propagate through the model, maintaining internal consistency and supporting structured trade-off analysis. By using standardized modeling languages (e.g., SysML v1 and v2), methods (e.g., OOSEM, SYSMOD), and tools (e.g., Cameo Systems Modeler, Capella), MBSE promotes technical rigor and cross-disciplinary collaboration (Friedenthal, Moore, & Steiner, 2014; Weilkiens, 2016; Object Management Group, 2023).

Beyond its engineering utility, MBSE offers unique pedagogical advantages. When reframed as a studio for simulation and exploration rather than mere compliance, MBSE helps students visualize systems holistically, test assumptions, and connect design decisions to real-world constraints. MBSE supports diagrammatic reasoning, stakeholder modeling, and systems-level thinking in ways that complement traditional analysis.

When aligned with STEAM principles, such as creativity, ethical reasoning, human-centered design, and aesthetic awareness, MBSE becomes a framework for integrating technical learning with broader educational goals (Yakman & Lee, 2012; Bequette & Bequette, 2012). Students move beyond function to consider usability, equity, sustainability, and social impact.

For example:

- Use Case Diagrams can incorporate underserved or marginalized stakeholders, encouraging inclusive design (Hess & Fore, 2018).
- Requirements Diagrams can explicitly include non-functional needs such as accessibility, privacy, or emotional response (Friedenthal et al., 2014).
- Activity and State Diagrams help students explore behavior under stress, ambiguity, or failure.
- Parametric Diagrams enable modeling of trade-offs where values like safety or sustainability must be balanced against performance or cost.
- Internal Block Diagrams (IBDs) support rapid experimentation with architectural alternatives.

MBSE serves not only as a technical modeling method but also as an intellectual space for values-driven engineering. It helps students develop both the fluency to build complex systems and the critical lens to examine who those systems serve, under what conditions, and at what cost.

STEAM

STEAM, which stands for Science, Technology, Engineering, the Arts, and Mathematics, extends the STEM model by recognizing the value of human-centered disciplines in technical education. Developed by Georgette Yakman (2008, 2012), the STEAM framework does not simply append art to science and engineering. It reframes education as an integrated process, where analytical reasoning, creative expression, emotional awareness, and functional design are treated as interdependent. Yakman emphasized that modern literacy requires understanding how disciplines interact, not just isolated subject competence.

Grounded in constructivist theory, STEAM encourages students to examine problems from multiple lenses, including technical, ethical, social, and aesthetic perspectives. Yakman and Lee (2012) described STEAM as a recursive model: science and technology are interpreted through engineering and the arts, all supported by mathematical logic. This structure allows learners to model systems in ways that reflect both technical validity and human relevance.

The STEAM approach cultivates empathy, creativity, and contextual awareness, capacities that are often overlooked in conventional STEM instruction. It promotes interdisciplinary thinking and challenges students to account for stakeholder needs, cultural context, and value-based trade-offs in design. STEAM-aligned instruction prepares engineering students to respond to the complexity of real-world systems, which rarely conform to strict disciplinary boundaries. Below is a list of non-technical STEAM values:

- Creativity and Imagination:
    - Encouraging novel approaches, original thinking, and artistic expression in problem-solving.
    - Valuing the process of ideation as much as the technical solution
- Empathy and Human-Centered Design
    - Understanding the needs, emotions, and lived experiences of diverse stakeholders.
    - Designing with and for people, not just systems or specifications.

- Ethics and Social Responsibility
  - Addressing the ethical implications of engineering and technology.
  - Promoting justice, equity, and sustainability in innovation.
- Critical Thinking and Reflection
  - Questioning assumptions and examining broader consequences.
  - Reflecting on one's role in shaping society and technology.
- Collaboration and Interdisciplinary Thinking
  - Working across disciplinary boundaries and valuing diverse viewpoints.
  - Fostering teamwork among technical and non-technical contributors.
- Communication and Storytelling
  - Translating complex ideas for broad audiences.
  - Using narrative and visualization to build understanding and engagement.
- Cultural Awareness and Inclusion
  - Integrating cultural perspectives into design and learning processes.
  - Challenging dominant paradigms by valuing marginalized knowledge systems.
- Personal Growth and Well-being
  - Cultivating self-awareness, mindfulness, and resilience.
  - Balancing technical pursuits with mental, emotional, and social wellness.

One aim of this paper is to identify strategies for unlocking creativity in systems engineering education. In STEAM education, creativity and imagination are not optional skills; they are central to how students learn to solve problems and design systems. These abilities help students move beyond standard approaches, consider multiple options, and generate ideas that are not strictly based on logic or calculation. Creativity is the skill of generating new ideas, discovering unexpected connections, and approaching problems from fresh perspectives. Imagination allows students to visualize how things might work, think through future scenarios, and mentally model system behavior. Together, creativity and imagination support the kinds of thinking required for design work, scientific exploration, engineering prototypes, and artistic expression , core activities across STEAM fields.

Design Thinking

INCOSE has increasingly recognized the value of Design Thinking as a complement to traditional Systems Engineering, particularly when confronting ambiguous, multifaceted, or human-centered design challenges (INCOSE, 2023). Rather than imposing a rigid methodology, INCOSE encourages the thoughtful application of Design Thinking principles, integrated with Model-Based Systems Engineering (MBSE), human-centered design practices, and systems architecture to enhance both technical rigor and user relevance (Madni & Sievers, 2018; INCOSE Vision 2035, 2022).

The following are key themes and integration points where Design Thinking informs INCOSE's evolving guidance:

Principle	Description	INCOSE Alignment
1. Empathize with Stakeholders	Understand user needs, values, and experiences through interviews, observation, and the development of personas.	The INCOSE Systems Engineering Handbook (v5) promotes stakeholder analysis, user needs elicitation, and modeling of operational context.
2. Define the Right Problem	Reframe the problem based on stakeholder pain points rather than technical symptoms.	Encourages early-stage concept exploration and operational scenario development in the definition of needs and requirements.
3. Ideate Multiple Solutions	Brainstorm broadly across disciplines before converging on solutions.	Supported by model-based trade studies, alternative architectures, and exploratory design modeling in MBSE.
4. Prototype Early and Often	Use low-fidelity models (including behavior models, mockups, or SysML diagrams) to explore alternatives and get feedback.	INCOSE promotes iterative model development in MBSE and rapid prototyping via digital twins or simulation.
5. Test with Real Users	Validate assumptions and designs by engaging users early and often.	Integrated into validation and verification planning and early concept demonstrations.
6. Iterate and Learn	Treat failure as feedback. Use systems thinking to evolve the design over time.	Promotes agile SE, incremental baselining, and learning cycles in complex projects.

METHOD

This paper draws on instructional design experience, applied modeling practice, and a targeted review of relevant literature to develop a practical approach for combining MBSE and STEAM in engineering education. Rather than framing this as a formal research experiment, the methods reflect a hands-on synthesis shaped by classroom observation, systems modeling workflows, and pedagogical reflection.

1. Review of Relevant Literature

A focused review of systems engineering education sources was used to identify common shortcomings in V-model-centered instruction. Particular attention was paid to critiques of traditional pedagogy, the evolution of MBSE methods, and the role of STEAM in interdisciplinary learning. Key works, such as those by Madni and Sievers on MBSE education, Dym et al. on design thinking, and Yakman and Lee on STEAM, helped anchor the argument for integration.

2. Development of Classroom Strategies

Ten instructional strategies were created based on real classroom practices, teaching workshops, and modeling sessions using SysML tools. These strategies were chosen to support both technical modeling and non-technical capabilities, such as creativity, ethical awareness, and systems thinking. Activities such as model sketching, persona-based design, and constraint-driven sprints were refined through iteration and practical application.

3. Linking Diagrams to Learning Goals

Each instructional strategy was mapped to specific SysML diagrams, such as Use Case, Activity, and State Machine diagrams, to illustrate how core learning values could be directly represented in the modeling work. The goal was to make abstract concepts, such as empathy or ethical reasoning, visible within concrete modeling tasks. This allowed students to connect what they were modeling with its significance.

4. Shaping Future Instruction

The strategies and tools outlined in this paper are meant to guide future curriculum pilots, classroom experiments, and faculty development programs. The approach reflects lived experience teaching MBSE in ways that engage students beyond just compliance or technical correctness. It's a step toward creating system models that are more thoughtful, responsive, and human-centered.

DISCUSSION

The Case for Change: Limitations of Traditional SE Pedagogy

Systems engineering education has historically followed the V-model, which promotes linear development stages from requirements definition through system verification (Forsberg et al., 2005). This model has established procedural discipline and reinforced standard practices in documentation, traceability, and lifecycle management. While effective for teaching structure and control, it has limited adaptability in the face of modern engineering problems that are increasingly dynamic, interdisciplinary, and socio-technical (Madni & Sievers, 2018).

A primary shortcoming of traditional pedagogy is its emphasis on process compliance over design exploration (Sheard & Mosterman, 2009). The framework leaves little space for iterative modeling, conceptual failure, or creative divergence, all of which are necessary conditions for innovation (Dym et al., 2005). By focusing narrowly on technical deliverables, students are often shielded from broader considerations such as stakeholder diversity, ethical constraints, or human-system interaction (Hess & Fore, 2018).

Additionally, this approach reinforces disciplinary isolation. Students are rarely asked to integrate perspectives from the humanities, social sciences, or the arts, even when designing systems with direct societal impact (Yakman & Lee, 2012). The result is a pedagogy optimized for technical precision but insufficiently equipped to prepare students for uncertainty, value-driven design, or cross-domain problem solving.

MBSE as a Platform for Creativity and Integration

Model-Based Systems Engineering (MBSE) is commonly introduced in academic programs as a technical method for managing system complexity, supporting traceability, and enabling structured analysis and design (Friedenthal et al., 2014). Through standardized modeling languages such as SysML, MBSE provides formal representations of system structure, behavior, requirements, and constraints (Object Management Group, 2023).

Unlike document-driven approaches, MBSE supports iterative design exploration. Students can analyze alternative architectures, simulate behavior, and investigate "what-if" scenarios within a shared modeling environment (Estefan, 2007). This capacity promotes early validation and fosters an experimental mindset, which is often absent from traditional engineering instruction. MBSE also enables conceptual integration by combining technical elements with stakeholder goals, operational context, and user experience, components that align closely with STEAM principles (Bequette & Bequette, 2012).

Modern MBSE tools such as Cameo Systems Modeler, Capella, and OpenMBEE facilitate collaborative model development. These environments allow student teams to co-develop, annotate, and refine models while maintaining traceability across the system lifecycle. The use of shared modeling platforms enhances communication, supports consensus-building, and mirrors real-world engineering team dynamics (Weilkiens, 2016).

MBSE also provides a means to visualize system attributes that are difficult to capture in traditional documentation. Parametric diagrams, behavioral models, and traceability views allow students to reason about performance trade-offs, stakeholder conflicts, and design constraints, including those rooted in ethics or sustainability (Madni & Sievers, 2018). By representing both quantitative and qualitative concerns in a single model, students gain a more complete understanding of systems as integrated socio-technical constructs.

In the classroom, MBSE shifts the focus from modeling for compliance to modeling for insight. When treated as a design medium, not just an analytical tool, it supports the development of creativity, systems thinking, and interdisciplinary reasoning. These capabilities are essential for future engineers tasked with designing systems that are both technically sound and socially responsible.

Embedding STEAM Values into MBSE Pedagogy

The STEAM framework encourages interdisciplinary thinking and human-centered design in parallel with traditional systems engineering practices (Yakman & Lee, 2012). MBSE provides a structured yet adaptable modeling environment that enables the operationalization of these educational priorities.

Use case diagrams enable students to represent a diverse range of stakeholders, including marginalized or underrepresented groups, promoting empathy and inclusive design (Hess & Fore, 2018). Requirements diagrams can be expanded to include non-functional constraints related to privacy, sustainability, accessibility, or social responsibility, reinforcing the role of ethics in technical decision-making (Friedenthal et al., 2014).

Activity diagrams support creative exploration of human-system interactions by allowing students to visualize process logic, decision points, and behavioral alternatives. Block Definition Diagrams (BDDs) and Internal Block Diagrams (IBDs) offer a platform for architectural experimentation, enabling students to develop and compare alternative subsystem configurations (Object Management Group, 2023).

Sequence diagrams and state machines provide tools for modeling temporal behavior, emergent properties, and user interaction sequences. These artifacts allow students to simulate how systems respond to varying conditions or operational disruptions, reinforcing system resilience and usability analysis (Weilkiens, 2016).

When integrated with pedagogical methods such as stakeholder role-playing, ethics mapping, and visual storytelling, these MBSE tools support the development of systems that reflect both technical integrity and social context (Dym et al., 2005; Bequette & Bequette, 2012). This integration positions MBSE not only as a framework for engineering rigor but also as a medium for values-driven system design.

The STEAM framework, which encompasses Science, Technology, Engineering, Arts, and Mathematics, promotes a more comprehensive approach to engineering education by emphasizing creativity, empathy, and interdisciplinary reasoning alongside analytical rigor. Its integration into systems engineering pedagogy enhances, not replaces, core technical competencies. When applied within an MBSE context, STEAM provides a structure for modeling systems that are technically valid, socially relevant, and aesthetically coherent.

- Use case diagrams serve as an effective entry point for incorporating stakeholder-centered thinking. By modeling roles such as users, operators, regulators, or underserved populations, students are prompted to consider system behavior from multiple perspectives. This approach supports inclusive design and reinforces the social context of engineering decisions.
- Requirements diagrams can incorporate non-functional constraints that reflect social, ethical, and cultural values. Attributes such as accessibility, sustainability, equity, and privacy can be explicitly modeled in SysML, reinforcing the legitimacy of value-driven requirements in formal system specifications.
- Activity diagrams enable students to visualize behavioral logic and decision points. These diagrams support exploration of alternative workflows, unexpected outcomes, and human interaction loops, encouraging adaptability and resilience in system design.
- Block Definition Diagrams (BDDs) and Internal Block Diagrams (IBDs) support the development and comparison of alternative architectural configurations. This promotes conceptual experimentation and reinforces the principle that systems are often refined through iteration rather than predefined solutions.
- Sequence diagrams and state machines provide tools for analyzing dynamic behavior and emergent phenomena. These artifacts allow students to simulate system performance

under various conditions and explore usability, resilience, and ethical scenarios through structured validation.

Instructors can reinforce STEAM integration through instructional methods such as:

- Role-based modeling to elicit diverse stakeholder perspectives;
- Interdisciplinary design exercises addressing public health, environmental sustainability, or social equity;
- Diagrammatic storytelling to communicate ethical trade-offs and user experience;
- Constraint-driven design challenges that treat aesthetic or societal values as part of the system definition.

By leveraging MBSE as a medium for value integration, educators can present systems engineering as both a technical and social discipline. STEAM-aligned instruction deepens, not dilutes, the engineering process by broadening the range of factors students are trained to model. Through this integration, students learn to engineer systems that perform, inform, and matter.

V. Instructional Techniques and Classroom Applications

To bring MBSE and STEAM together in real classroom settings, instructors need to move beyond theory and adopt practical methods that connect modeling with creativity, systems thinking, and human-centered design. MBSE's structure, visual, iterative, and modular, makes it ideal for exercises that go beyond compliance and instead emphasize experimentation, reflection, and collaboration. The strategies below are designed to help students explore ideas early, test concepts through modeling, and link technical design with social, ethical, and aesthetic concerns. These are not generic activities. They are tailored for the MBSE environment and focus on how students think, design, and communicate through models.

1. Early Concept Sketching and Informal Modeling

Before using formal MBSE tools, students should start by doing rough thinking on paper, whiteboards, or sticky notes. These early sketches help define the system boundary, purpose, and users. This stage is about exploring ideas, not refining them. Later, students convert the concepts into Block Definition Diagrams or Use Case Diagrams using SysML.

2. Scenario-Based Design with Personas

Students are given user personas such as emergency responders or individuals with disabilities. These roles help them view the system through another person's eyes. They develop user stories and translate those into Use Cases and Activity Diagrams. The exercise ties technical design to real human needs.

3. "What If?" Divergence Modeling

Students are asked to redesign a system under unexpected conditions, such as operating in extreme weather or with limited power. This forces them to revisit design assumptions and build flexible models. Internal Block Diagrams, Parametric Diagrams, and State Machines help show how the system would adapt.

4. Parallel Architecture Modeling

Students model several system options that meet the same core need but with different structures or trade-offs. They compare the models using a matrix that includes metrics such as cost, complexity, and resilience. SysML helps them show and justify each architecture. This prevents early tunnel vision in design.

5. Model Jams and Design Sprints

Students work in teams under a time limit to model a solution to an open-ended problem. The goal is quick thinking, not polished output. They use lightweight SysML diagrams, such as Use Case, Sequence, or Package Diagrams, to capture concepts quickly and gather feedback. This builds modeling fluency and design confidence.

6. STEAM Fusion Assignments

Students receive technical challenges that include creative or cultural constraints. They may be asked to design for beauty, emotional response, or community values. They use SysML to link technical models to these human elements through annotations and constraint notes. The system must work and also mean something.

7. Human-System Interaction Modeling

Students model how people interact with the system under real conditions, including stress, fatigue, or confusion. Activity Diagrams, Sequence Diagrams, and State Machines are used to represent these interactions. The result is a deeper view of system behavior that includes human unpredictability.

8. Unconventional System Design Challenges

Students are tasked with modeling complex or abstract problems like reducing burnout or restoring public trust. Using Requirement and Parametric Diagrams, they explore how systems can be shaped to support social and emotional outcomes. These assignments expand the definition of what a system can address.

9. Design Journals and Reflection Logs

Throughout the project, students keep a written record of their design process. They explain what they tried, what changed, and why decisions were made. They must link their reasoning to specific model elements. The log serves as a map of how their thinking evolved and adds accountability to their work.

10. Prompted Ideation with AI Tools

Students can use AI tools to generate starter ideas like sample use cases or edge conditions. They are required to revise and critique those ideas before modeling. MBSE tools are then used to refine and validate the concepts. AI serves as a support tool, not a shortcut.

The strategies outlined here do more than teach students how to build MBSE diagrams. They change the way students approach systems thinking altogether. Each method is designed to help students question their assumptions, engage with real users or scenarios, and treat modeling as an active design space rather than a recordkeeping exercise. The classroom becomes a place where technical rigor and creative exploration go hand in hand. Students learn to hold structure and ambiguity simultaneously, modeling for both performance and meaning. When these techniques are incorporated into regular instruction, MBSE becomes a tool not just for analysis, but for shaping ideas that truly matter.

VI. Conclusion and Future Directions

Traditional systems engineering education must evolve to meet the demands of increasingly complex and unpredictable socio-technical environments. While the V-model remains a strong foundation, grounded in traceability, discipline, and lifecycle control, it is no longer sufficient on its own. It does not prepare students to handle ambiguity, address human needs, or reason through the ethical trade-offs embedded in modern system design.

This paper has made the case that integrating Model-Based Systems Engineering (MBSE) with the interdisciplinary values of STEAM is not a departure from technical rigor but an expansion of what rigor includes. When MBSE is treated as a platform for exploration rather than just compliance, it gives students tools to model uncertainty, assess conflicting requirements, and incorporate ethical, aesthetic, and social constraints directly into their designs. Formal modeling languages like SysML can still capture structure and behavior, but they can also represent human context when instructors intentionally use them in this way.

Creative modeling strategies support this shift. Early sketching, persona-driven modeling, design sprints, AI-assisted ideation, and reflection logs allow students to move between divergent and convergent thinking without losing modeling discipline. These activities demonstrate to students that MBSE is not only about documenting decisions, but also about shaping them.

Moving "beyond the V" is not about discarding engineering structure. It's about redefining what counts as engineering. Future efforts must include pilot courses that fuse MBSE and STEAM, faculty training focused on creativity-driven pedagogy, and research on how modeling supports both technical accuracy and socio-technical insight. LLM-powered modeling tools present new opportunities for helping students explore edge cases and generate alternatives early in the design process. An open-access library of STEAM-aligned MBSE examples could help scale these methods across institutions.

The future of systems engineering education depends on engineers who can model not only how systems function but also why they matter. That shift begins in the classroom, when students are given the tools, language, and freedom to model with both precision and purpose.

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TOOLS TO MANAGE COMPLEXITY

A case study in teaching Model Based Systems Engineering (MBSE) & Requirements Management to non-systems engineers

Introduction: As the complexity of challenges and technology continues to escalate, it is imperative that we equip future engineers with the necessary skills, including non Systems Engineers (SE). Requirements management and MBSE tools hold promise for enhancing productivity, sustainability, and risk mitigation on complex projects. However, the effort to expand MBSE utilisation is often met with concerns over model, tool and training complexity. Many industries hold a perception that SE and MBSE do not have an acceptable Return on Investment (ROI).

Method: This case study examines MBSE training conducted with 75 students with no prior experience in Systems Engineering. The program comprised of 3 one-hour lectures and 2 two-hour workshops, supplemented by up to 30 hours of project-based learning using Spicy-se.com for requirements, component and interface modelling and Miro.com for activity, class and state transition diagrams. Of the 28 respondents to the survey, previous educations was split between Engineering (40%), Computer Science (39%), and Maths, Physics and Other (7% each).

SPICY SE + miro

It is possible to obtain MBSE understanding for non-systems engineers (if you keep the tooling simple)

Student confidence can be achieved in under 40 hours, especially in Requirements & Component modelling

Spicy-SE & MIRO do NOT replace advanced MBSE tools (yet) especially for impact analysis & re-use

Spicy-SE & MIRO address ROI concerns & empower MBSE utilisation across disciplines through simplicity & AI use

Results & discussion: Spicy-SE supported a high overall understanding in terms of writing Specific, Measurable, Achievable, Relevant and Time-board (SMART) requirements in addition to layered component diagrams. Students found traceability and interface management harder with 16% achieving only a basic understanding. Surprisingly, some students only achieved a basic understanding of activity diagrams in Miro (20%) though the challenge with more complicated class diagrams (12%) and state transition diagrams (16%) was expected.

Conclusions & future work: New simplified tooling shows promise to break down the traditional barriers of MBSE adoption, with future work focusing around testing the tooling on more complex projects, verification and the potential of Artificial Intelligence.

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The SE Competency conundrum: How SySTEAM, Micro-Learning, and TMC are (re)Writing the Systems Engineer's Playbook

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Abstract

Many companies strive to develop a strong **Systems Engineering competency** while fostering a **self-sufficient community** of like-minded engineers. As an engineering services provider, **TMC** faces the dual challenge of staffing its customers' projects with Systems Engineering expertise while simultaneously nurturing its own engineers, often from very diverse educational backgrounds. This poses a challenge since current educational systems have historically struggled to prepare the engineers of the future.

This paper explores strategies for establishing a **sustainable Systems Engineering competency** and community, addressing **TMC Italy's 2020-2030 initiative** to identify, develop, and deploy systems engineers for both internal growth and external projects. The authors examine insights from **TMC's experience**, discussing how learning models such as **Bloom's Taxonomy and Kolb's Model** shaped their approach and how SySTEAM becomes a critical path for the future educational system on which TMC depends.

The study highlights the **SEPD program**, an **ad hoc Education, Training, and Certification (ETC) framework**, currently structured around a **four-phase training roadmap** and supported by tools like the **Systems Engineering and Certification Clinic**. It explores methods for integrating **skills, traits, and theories** from various schools of thought to **cultivate a Systems Engineering mindset** in collaboration with customers and educators/trainers. The program includes SySTEAM as both a learning and knowledge dissemination method allowing engineers to transfer their knowledge and build the students awareness of what Systems Engineering has to offer to them, irrespective of their chosen work future. Their involvement in SySTEAM is thus both a motivator and a disseminator.

The advent of **micro-learning and leveraging modern learning approaches** has also afforded that Systems Engineering training programs need to adapt to amplify adoption, starting from academia. Two SySTEAM case studies are presented, a technical vocational college and a Magnet school specialising in STEM related studies including the arts and humanities. The authors recognise also that educating and training starts much earlier, hence welcoming initiatives such as SySTEAM, Vision 2035 and FuSE. Further, the authors propose shifting to a **dynamic ETC matrix approach**, expanding subject areas and engaging a broader range of experts including academia, to further **enhance Systems Engineering competency development** and bridge the gap between the **educational and industrial systems.**

Keywords: Bloom, Kolb, Systems Engineering, SySTEAM, Competency, TMC, INCOSE

Introduction and Overview

Many systems engineers are traditionally taught a reductionist approach: break-down problems, rearrange-fit the pieces, and find a functional solution that fits the system requirements. This 'systematic' method, historically common and notoriously bottom-up, contrasts with a 'systemic' top-down perspective that starts by understanding and satisfying the needs of the stakeholders.

Moreover, incessant system complexity, use of AI and MBSE [Henderson et al. 2023], shorter development times, and education/competencies that notoriously lag demand infers that the reductionist approach falters or fails to deliver. A lack of Systems Engineering competencies hinders both the growth of a robust systems culture and project success. Two reactions appear to be currently at play hyper-specialise the engineers or generalise them and create a hybrid systemic-systematic engineer and fuse him/her as the technical leader. A sort of 'Frankenstein' in the hope for better days. Stating the facts helps us realise the massive challenge in front of us. INCOSE's current membership is 26000+ and about 20% of these are SEP certified with a growth rate of roughly 3-5%. The demand is much higher, at least double [MRINetwork], implying that we are losing ground and we have no other option but to retrain the engineers we already have and the ones still in the education system when these arrive. Over the period of 2020-2025 in which the SEPD program was executed TMC Italy grew their workforce by a factor of 4, at least 1 in 10 are systems engineers, albeit recycled ones. The program has so far trained about 60 engineering staff of which 15% are SEP certified. None of this staff had any formal SE training, the majority aged under 40 and recognised personal development a key retention and success factor. Perhaps more insightful is that at a global level TMC will grow by a factor of 3 its current workforce of roughly 3000 worldwide.

Our customers are facing similar staffing challenges but made worse by an aging engineering workforce and unprepared younger generation stuck in between systemic-systematic counter forces together with hyper-emphasis on skills and satisfying market demand rather than guiding and building the workforce of the future [CESAER, 2024].

Academically speaking the current generation is either too specialised or too generalised even in their engineering discipline. Engineering academia appears to be in a similar predicament and standing but perhaps made worse by having to sit in between chasing academic performance and work placements for their students.

A further challenge is finding and cultivating SE talents and building an identity and community to sustain them. From the outset the SEPD program has been about building a mindset through personal development, skills and traits. Providentially TMC's business model provides adequate help:

- ☑ TMC engineering staff are assigned a non-engineering coach from day one. This ensures that individuals realise who they are, the talents they possess and how to leverage them for the benefit of themselves, TMC and of course, its customers. Traits and qualities come before skills (hard or soft) and systems engineers are good examples of this train of thought.
- ☑ TMC engineering staff are expected to be entrepreneurial in spirit and practice. The talent selection process is geared to find such aptitude and the *employerneurship* model ensures staff see the fruits of their efforts also financially.
- ☑ The annual pro-capite training budget. Staff use this budget for their training of choice, whether this be about a skill or competency or just general participation in say, a trade fair.
- ☑ The business model also provides another opportunity and that is to set-up ones' own enterprise (TMC's *entrepreneurial* lab) which is co-funded by the person(s) and TMC.
- ☑ TMC's Business Cell approach led to the creation of the SEBC in 2023 by SEPD trained engineers and other sympathisers who recognised the need for a SE community of like-minded people.

A further significant issue is that TMC is in the front-line not just in finding the resources but also the right ones and then subsequently nurturing their SE talent. While INCOSE educational initiatives like SySTEAM and FuSE are valuable, they are long-term, whereas industry demands immediate resources. Most systems engineers today come from other disciplines, making re-training time-consuming and sometimes ineffective—especially when balancing systemic thinking with systematic execution. Workplace SE education requires reshaping engineers, possibly with certification. While INCOSE's SEP certification is recognized, companies may choose alternative paths by '*growing their own systems engineers',* leveraging standards like ISO/IEC24773 and INCOSE's competency framework [INCOSE, 2018].

ISO/IEC 24773-1:2019, Part I: General Requirements	ISO/IEC 24773-2:2024, Part II: Guidance regarding Knowledge, Skills and Competence in Certification-Qualification Schemes	ISO/IEC 24773-3:2021, Part III: Systems Engineering	ISO/IEC 24773-4:2023, Part IV: Software Engineering

Table 1 - ISO/IEC24773 Series concerning SE and SWE competency and certification

This has led to the need for SEPD program, a 4-stage SE development framework starting with SE training, including its sustaining such as the SE and SEP clinic, SE career ladder. A further aspect of ETC concerns integrating Bloom's taxonomy and Kolb's model to foster an outcome-centred approach [Zhang et al., 2023] e.g., active learning, mentoring others, setting-up the premise for SEP certification. The training is also open to TMC's customer base with examples in defence, medical and electronics.

Reflections on TMC Italy's SE Journey: Lessons and Milestones

Bloom's Taxonomy and Kolb's model

Bloom's Taxonomy developed in the 1950s [Bloom, 1956], is a 6-level hierarchical classification system and framework that categorizes an individual's educational and learning objectives in terms of a self-paced knowledge journey. The framework aids the design of learning activities while helping to assess a student's understanding at different levels of thinking. for the topic at hand. It is an integral part of the INCOSE SEP certification with the first two levels (remembering and understanding) the basis of the SEP knowledge exam while the SEP program covers all six levels.

Kolb's model [Kolb, 1984] provides a powerful model for learning through a cycle of experience, reflection, conceptualization, and experimentation. The model ensures that learners develop adaptive expertise, a necessity in engineering complex systems but also monitoring and revisiting project outcomes, reflect on process gaps, adapt methods, apply improvements and so forth. Engineers of all ages benefit from this experiential cycle, especially with an outcome-based educational approach.

Kick-starting and Growing the SEPD Program from 2020 to 2025

The SEPD program was kick started and grown through four steps:

1. Assessment of SE needs and expectations of the TMC customer base, especially from a skills and traits viewpoint, and how these link to TMC's five pillars of *employeneurship*: 1. Business Cells, Individual Profit Sharing, Long-Term Working Relationship, The Entrepreneurial Lab and YOUniversity-Coaching).
2. Establish the skills and traits of the SEPD program trainees and how they compare to step 1. This also included aspects such as age, specialization, experience, current and past projects. TMC business staff were involved to ensure a balanced assessment and the coaching aspect becomes an integral part of helping personnel understand their personal identify through their traits.
3. Estimate SEPD program investments and costs e.g., purchase of SE standards, INCOSE training material etc. Each TMC *employerneur* is allocated a personal budget that the person allocates to activities deemed useful including visiting trade fairs, conferences, training courses etc. As from 2024 the SEPD program cost was 12.5% to 30% of this budget depending on SEP certification, which remains optional. The sustaining of the SE training and SEP certification costs is covered by TMC.
4. Preparation of four SEPD program roadmaps namely: Training, On-the-job Training, Training others and Training the Trainers. The intention was clearly to prepare engineers to become not just systems engineers but also provide them with a deeper understanding through a dedicated SE career ladder. In a way this was trying to close the gap in lack of adequate academic training in SE. In 2025 the overall SE training amounted to over 140 hours covering 20 topics, from Introduction to SE to SEP certification. The growth of the number of topics is shown next:

2020-2021	2021-2022	2022-2023	2023-2024	2024-2025
13	13	13	15	20

Table 2 – Progression of SE Training modules in the original SEPD program

Hard/Soft skills versus Traits schools of thought—time to change the paradigm

Hiring and training in enterprises are heavily focused on either hard or skills or both. However, from experience we know that while skills are crucial to carry out tasks it is how these tasks are tackled (especially with others involved) that often dictates their success or failure. Simplifying, skills are about the 'what' while the 'how' is about how the individual exploits his/her traits to carry out the tasks. Further. skills are associated with responsibility while traits are about accountability irrespective of task, role and/or challenge. Interestingly when enterprises orient towards to traits the 'how' moves away from satisfying tasks to providing results i.e., deliverables. This bears two schools of thought, that of skills and that of traits. Both schools are intertwined with TMC's employerneurship model.

Indeed, when the value of an individual's traits surface through awareness and deliberate fostering e.g., mentoring and coaching, they adapt better to challenges typical of today's systems. However, since enterprises today are still skills-driven organizations, especially when hiring, responding to project staffing requests requires satisfying skills while putting the individual and his/her personal development at the forefront. This requires understanding the hiree, helping him/her to do likewise while addressing hirer needs all in the context of the generational spread and shift, we face today:

Generation X (mid.60s to early 80s)	Generation Y (Millennials)	Generation Z (1997 to 2012)
Favour independence, work-life balance, adaptability, and a pragmatic approach to life. Renowned for resilience, financially responsible, ownership, responsive and comfortable with technology.	Tech-savviness, a strong desire for purpose and meaning in work and life, and a preference for flexible and collaborative workplaces. Renowned for valuing diversity, inclusion, being socially responsible and striving a balance between work and leisure.	Crowned as digital natives, highly tech-savvy, diverse, and pragmatic. They are also entrepreneurial, value authenticity and individuality, and are socially conscious

Table 3 – Hiree Characteristics versus Generational Spread

The hiring process needs to take into account generational differences, matching hiree (personal) and hirer (project) development needs and responding to hiree skills and traits such as:

Hard Skills	Soft Skills	Traits	
Are about the technical knowledge the person has gained through academic and professional training and/or working experience.	Are about the habits and behaviours of the person often inspired by circumstances.	Are about distinguishing qualities or characteristics, personality features of the person. Many are tied to upbringing and family education.	
○ Academic specialization such as Mech. Engineering ○ Foreign Languages ○ Coding/Programming Languages ○ SEP Certification ○ Design e.g., CAD, CFD, MBSE	○ Communication ○ Teamwork ○ Problem-solving ○ Critical thinking ○ Time management ○ Conflict management ○ Negotiation	Lighter: ○ Integrity ○ Loyalty ○ Devotion ○ Kindness ○ Sincerity ○ Patience ○ Resourceful	Heavier: ○ Confidence ○ Determination ○ Charisma ○ Authority ○ Enthusiasm ○ Risk taking ○ Ownership
Often linked to active learning	Often linked to the behavioural learning	Traits are split into 3 categories: a). Cardinal, form your recognition b). Central, form your core customs c). Secondary, are your preferences	

Table 4 – Comparing Hand and Soft skills to Traits

The SEPD program combines the development of skills and nurturing of traits through its training and correct deployment and also by allocating the 'right' resources to the right project. We therefore leverage two schools of thought, Skills-based and Traits-based in combination with a four-stage learning journey: each stage being timed to suit the personal development of the engineer. Sometimes the engineer starts with a couple of competencies e.g., requirements, other times anew.

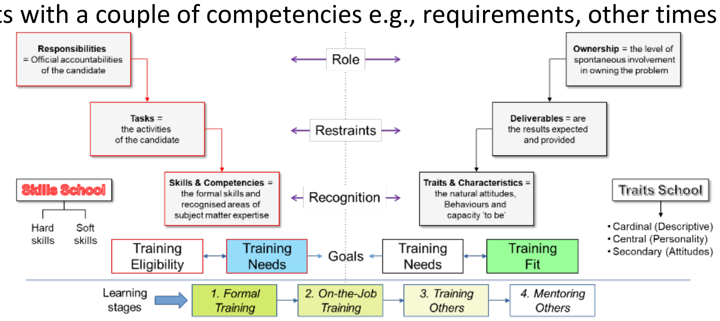

Figure 1 – Skills and Traits schools of thought in the SEPD program

SEPD Program Snapshots

The 4-stage SEPD deployment process

The program starts with formal module-driven training then applying this knowledge in the workplace. Stages 1 and 2 can also happen concurrently or partially overlap depending on the project and its challenges. Subsequently the trainee transfers the knowledge and experience gained to peers and subordinates and concludes by mentoring others to do the same.

The journey is not linear but sequential and currently the majority of trained TMC engineers are between stages 2 and 3 (notably those with SEP certification), and depending on competency may well be in the initial part of stage 4 e.g., MBSE mentoring.

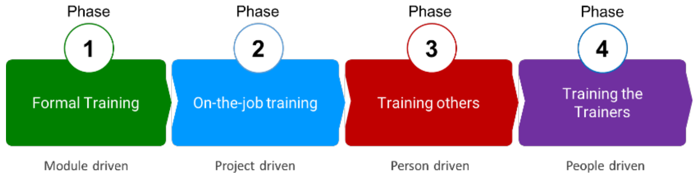

Figure 2 – 4-stage SE Personal Development program

During phase 1 the trainees are exposed to a very broad but detailed view of SE with progressive learning challenges and competencies, all of which are topic-driven. Stage 1 is split into three parts: 1.preparatory, 2.pillars and 3.specifics ending with the option to go for SEP certification [INCOSE]. All SEPD raining starts off with a kick-off and an introduction to SE.

Idea Generation and Product-breakdown as a Training approach

To fortify SE concepts during part 1 each trainee ideates an idea concerning a system (product or service) and answer 4 fundamental questions: 1. what is your idea? 2. who is it for? 3. how will you make money from it? and 4. why is it needed?

Each trainee then presents his/her idea to the rest of the class using an elevator speech [Sjodin, 2012] approach and subsequently the class votes anonymously through a dedicated on-line questionnaire. The results are then shared and each ideator can propose modifications, updates or just simple park/abandon his/her idea. This is further integral part of the SEPD program is to promote the use of product breakdowns, widely used for benchmarking, reverse engineering, and system analysis. In the program, trainees select a product with at least five parts, disassemble it with simple tools, and analyse its architecture using diagrams and conceptual mapping. Group sessions deepen understanding by exploring design choices and hence enhance their comprehension of the system.

SE Clinic and TMC 'G' guides

As trainees learn the SE basics many doubts surface. These can be derived from their projects, some from experience (or lack of it) and some due to the need to personalise solutions and so forth. To this end the 'SE clinic' provides a sort of one-stop consultancy where trainees can pose specific SE questions. A further learning tool are quick references known as TMC 'G' guides that tackle specific SE topics. Trainees are invited to co-author with the trainer or write their own SE guides.

Aligning Learning modes with modern delivery tools

Since everyone has one or more preferred learning modes, the SEPD program leverages exercises based on the following learning/learner modes [Hassan and Rahman, 2022]:

Behaviourist 1	Provoking reactions from trainees and detecting any changes in behaviour, thus invoking a reaction and alteration of behaviour.
Cognitive 2	Stoking diverse memories, motivation, and thought processes to form patterns, integrating social and cognitive learning as in teamwork.
Constructivist 3	Interpreting and encoding information through personal insight, learners analyse, refine, and adapt ideas based on experience.
Active 4	Learners are actively engaged or involved in learning-by-doing, idea generation, handling physical artifacts like products.

Table 5 – Learning Modes and Description

Due to the geographic dispersion of TMC trainees this has sanctioned principally the use of virtual and self-learning. Classroom learning should be promoted first as it leverages all four learning modes, lessens the burden on developing ad hoc training methods/tools and increases efficiency/efficacy.

Learning Type	Learning Mode
Virtual	2 and 3
Self	2, 3 and 4
Classroom	All 4 learning modes

Table 6 – Learning Types versus Learning Modes

The Next SEPD program 2025 to 2030

Three of the major shifts that has motivated TMC to review its SEPD program are the:

i. rise of micro-learning/credentials
ii. extension and speciality of training content due the evolution of SE e.g., MBSE, Design and Systems Thinking;
iii. need to extend basic SE training to all engineers, regardless of their discipline e.g., SWE, implying that the program requires different formats such as:
   - INCOSE Handbook-centred based all 6 parts of V5, with up to 30 modules, 1 module/session, 2hr per session. This grossly fits with an equivalency approach used by INCOSE with academia and fits well with subsequent SEP certification by both TMC and its customers.
   - A SE topic-driven approach that aligns well with traditional training but is based on a continuous year-round cycle of weekly training that affords the following characteristics:
     - Each module has three parts (time split 50:25:25): Theory, Exercise(s), Round-table discussion;
     - Trainees can align their availability with the weekly topic;
     - Trainees can align their workplace needs with the weekly topic;
     - Shorter and focused training with an intent to complete both a candidate's profile and dossier;
     - Alignment with INCOSE's PDU system of SE continuous training;
     - Involve TMC staff and invited specialists to share their knowledge by becoming module trainers;
     - Invite practitioners and guest speakers to tackle specific bur correlated SE topics e.g., cyber-security but not covered in the program.

An excerpt of the 2025-2030 program with 30 modules is shown below:

Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Intro. to SE	SE Concepts	Sys. Foundations	ConOps to OpsCon	Design-Systems Thkg.	System Design-Analysis
Week 7	**Week 8**	**Week 9**	**Week 10**	**Week 11**	**Week 12**
SE Standards	SE LC & Models	Needs & Reqs.	Req. Mangt.	Risk Analysis	Ris Mngt.
Week 13	**Week 14**	**Week 15**	**Week 16**	**Week 17**	**Week 18**
Sys. Architecture	SE Processes	Process Tailoring	Verification	Validation	System Integration
Week 19	**Week 20**	**Week 21**	**Week 22**	**Week 23**	**Week 24**
Interface Mngt.	Config. Mngt.	Intro. to SysML	Intro.to MBSSE	SE Governance & Plng.	SE Analyses-Methods
Week 25	**Week 26**	**Week 27**	**Week 28**	**Week 29**	**Week 30**
SE Case studies	R & R in SE	SE and QMS	SE Toolkit	Future of SE	SEP Certification

Table 7 – SE Topic-driven to SE Training

Whatever the format or steps taken these need to be in-line with TMC's *employeeneurship* model [TMC] and needs of its customer base (present and future) and initiatives such as FuSE [INCOSE, 2023].

One must also not forget that both systems engineering and the systems engineers need a playbook to settle both strategies and tactics as well as actionize their outcomes as proposed in table 8:

Actionable Guidance	Standardization & Consistency	Best Practices & lessons Learned	Efficiency & Speed
Scalability & Onboarding	Empowerment	Adaptability	Clear Goals & Scenarios

Table 8 – Systems Engineering and Systems Engineer's Playbook

Conclusions

Educating, training and certifying engineers in the field of Systems Engineering is a challenge that many enterprises face. Until the educational system is capable of supplying engineers with the necessary Systems Engineering knowledge, enterprises need to develop and train their own. This is a medium to long-term investment and not just about skills, rather traits and skills. Quite rightly the Royal Academy of Engineering [2024] suggests that we need to rethink engineering and technology

skills to ensure that both people and our planet thrive (perhaps the ultimate complex system of all). Ferreira et al. [2024] expose the challenges and strengths identified by different institutional stakeholders for the development of the engineering curriculum and address STEM and STEAM.
To this end TMC Italy has decided to 'grow its own systems engineers' (since 2020), aligning this decision with its employeneurship business model while fostering the personal development of the individual (internal and external). TMC has decided to do this through a dedicated and original program that mixes education with training capturing also the attention of its customers. The advent of things such as micro-learning and leveraging modern learning approaches has also afforded that SE training programs need to adapt to accelerate and amplify adoption (hence the playbook proposal). The authors recognise also that educating and training starts much earlier, hence welcoming initiatives such as SySTEAM, Vision 2035 and FuSE. The new SEPD2025-2030 is not only a realignment but a response to the challenges we face.

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Stories to Self: Cultivating STEAM Self-Efficacy and Engagement through Storytelling

By: Federica Robinson-Bryant, Alice Squires and Stueti Gupta

Abstract

This paper explores the profound impact of storytelling, specifically through the "Letters to My Younger Self" (LTMYS) framework, in cultivating self-efficacy, persistence, and interest in Science, Technology, Engineering, Arts, and Mathematics (STEAM) disciplines among high school students and young adults. The concept of writing reflective letters from experienced professionals to their past selves has been widely adopted across various corporations and organizations as a powerful tool for mentorship, professional development, and intergenerational knowledge transfer. Empirical data from diverse initiatives consistently underscore the utility of such narrative approaches in enhancing confidence, clarifying career pathways, and demystifying the realities and challenges within professional fields.

The Empowering Women Leaders in Systems Engineering (EWLSE) working group, within the International Council on Systems Engineering (INCOSE), has actively championed its own LTMYS initiative, compiling authentic narratives from systems engineering professionals. Analysis of readership engagement and qualitative feedback from participants reveals compelling evidence of the effort's ability to inspire young people, bolster their self-belief, and provide vicarious mastery experiences. These insights are instrumental as we develop Volume 2, informing strategies to optimize its content and maximize its reach and impact within the target demographic. By sharing personal journeys and lessons learned, LTMYS effectively bridges the gap between current aspirations and future realities, offering relatable role models and practical wisdom.

This paper highlights how leveraging the inherent power of personal narratives through LTMYS serves as a vital intervention to strengthen the STEAM pipeline by nurturing the foundational elements of self-efficacy and sustained engagement. Ultimately, this approach not only inspires but also provides a roadmap for navigating the complexities of STEAM careers, fostering a resilient and engaged talent pool. We will conclude with practical tips and actionable suggestions for educators, mentors, and organizational leaders to effectively integrate LTMYS into their programs. These include activity ideas for classroom discussions, mentorship pairings, and curriculum development, empowering participants to proactively use these powerful narratives to motivate and guide the next generation of STEAM innovators.

I. Introduction

Stories are the fundamental threads that inform our understanding of the human experience, shaping perceptions, transmitting knowledge, and inspiring action across generations. From ancient myths to modern memoirs, narratives possess an unparalleled power to connect, educate, and motivate. In the contemporary landscape of Science, Technology, Engineering, Arts, and Mathematics (STEAM) education, a critical challenge persists: engaging high school students and young adults, particularly those from underrepresented groups, and fostering their self-efficacy and persistence within these complex disciplines. Traditional pedagogical methods, often didactic and abstract, frequently fall short in conveying the human element, real-world relevance, and diverse pathways inherent in STEAM careers.

This paper introduces "Letters to My Younger Self" (LTMYS) as a novel storytelling intervention designed to bridge this gap. LTMYS leverages the authentic voices of experienced systems engineering professionals, who reflect on their career journeys and offer insights to their past selves. This unique narrative approach not only demystifies the realities and challenges within professional fields but also provides relatable role models and practical wisdom. This paper argues that the LTMYS framework profoundly cultivates self-efficacy, persistence, and interest in STEAM disciplines. We will explore the theoretical underpinnings of storytelling in education, detail the successful implementation and impact of the Empowering Women Leaders in Systems Engineering (EWLSE) working group's LTMYS initiative, and finally, outline actionable suggestions for educators and mentors to integrate this powerful approach into their programs.

II. The Power of Storytelling in STEAM Education

The efficacy of storytelling in educational contexts, particularly within STEAM, is rooted in robust psychological and cognitive frameworks. At its core, storytelling directly influences Albert Bandura's (1997) concept of self-efficacy, which refers to an individual's belief in their capacity to execute behaviors necessary to produce specific performance attainments. Bandura identified four principal sources of self-efficacy: mastery experiences, vicarious experiences, verbal persuasion, and emotional arousal. The LTMYS framework, through its design, significantly leverages vicarious experiences and verbal persuasion. When young readers engage with personal narratives of systems engineers overcoming challenges and achieving success, they gain vicarious mastery experiences, seeing themselves reflected in the journey. The advice and encouragement offered by the authors serve as powerful verbal persuasion, reinforcing the belief that success is attainable. Strong self-efficacy, in turn, is a critical predictor of greater engagement, persistence in the face of obstacles, and ultimately, higher achievement in academic and career pursuits.

Beyond self-efficacy, narrative psychology highlights how stories make complex information more accessible, memorable, and emotionally resonant. Research suggests that digital storytelling, for instance, can positively influence STEM interest and perceptions of intellectual stereotypes among middle school students (El Chaabi & Younes, 2025). Stories inherently provide a narrative structure that appeals to causality and goals, making content more interesting, understandable, and memorable (Spagnolo, Bolondi, Corni & Drius, 2024).

This is particularly vital in STEM, where abstract concepts can often deter nascent interest. Personal stories from professionals humanize the field, offering relatable role models and demystifying careers that might otherwise seem distant or intimidating. They challenge intellectual stereotypes often associated with STEM, illustrating that diverse backgrounds and thought processes are not only welcome but essential. Narratives connect abstract STEM concepts to real-world applications, making them meaningful and tangible, thereby capturing curiosity and fostering emotional connections that make learning enjoyable.

Moreover, reflective practice, a core component of the LTMYS framework, plays a crucial role in personal and professional development. Reflective writing enhances self-knowledge, critical thinking, problem-solving abilities, and overall personal growth (Sudirman et al., 2024). Studies indicate that students who regularly engage in self-reflection demonstrate increased self-confidence and self-satisfaction (Wang et al., 2017). While reflective practice can sometimes be perceived as "non-scientific" by some STEM students, and thus requires careful scaffolding to be truly effective, its long-term benefits in fostering confidence and self-knowledge are well-documented (Zarestky et al., 2022). By encouraging both the writing and reading of reflective narratives, LTMYS cultivates a deeper understanding of the journey into systems engineering, preparing individuals not just with technical knowledge, but with the resilience and perspective needed to thrive. The narrative format allows for the exploration of emotional arousal, as readers connect with the struggles and triumphs of the authors, fostering empathy and a sense of shared human experience within the professional journey. This emotional engagement can further solidify interest and commitment to the field.

III. "Letters to My Younger Self": Origins and Corporate/Organizational Applications

The concept of "Letters to My Younger Self" has emerged as a powerful reflective tool, gaining traction across various sectors for personal growth, mentorship, and intergenerational knowledge transfer. This format encourages experienced individuals to distill their life and career lessons into a narrative addressed to their past selves, offering advice, warnings, and encouragement in a friendly tone. This introspective process often yields profound insights that resonate deeply with both the author and the reader, creating a unique form of mentorship that transcends geographical and temporal boundaries. The inherent intimacy of a letter allows for a level of candor and personal reflection that might be absent in more formal presentations or textbooks.

Numerous corporations and professional organizations have adopted this format to foster guidance, particularly in fields where attracting and retaining diverse talent is a priority. The International Council on Systems Engineering (INCOSE), for example, has championed its own "Letters to My Younger Self" (LTMYS) eBook (2022) through the Empowering Women Leaders in Systems Engineering (EWLSE) working group. This publication serves as a compendium of authentic narratives from systems engineering professionals worldwide, sharing insights about their lives and careers to inspire future generations, with a particular emphasis on encouraging women in STEM. As Kerry Lunney, former INCOSE President, notes in the foreword to Volume 1, the experience of writing these letters is "cathartic," allowing authors to accentuate positive aspects of their journey and recognize the collective impact of seemingly small events. The diverse perspectives from 25 contributors across 9 countries offer invaluable guidance, providing a transparency not often found in traditional career guides. As Figure 1 depicts, this collection demonstrates the power of intergenerational knowledge transfer, allowing the wisdom of seasoned professionals to directly inform and guide the next generation.

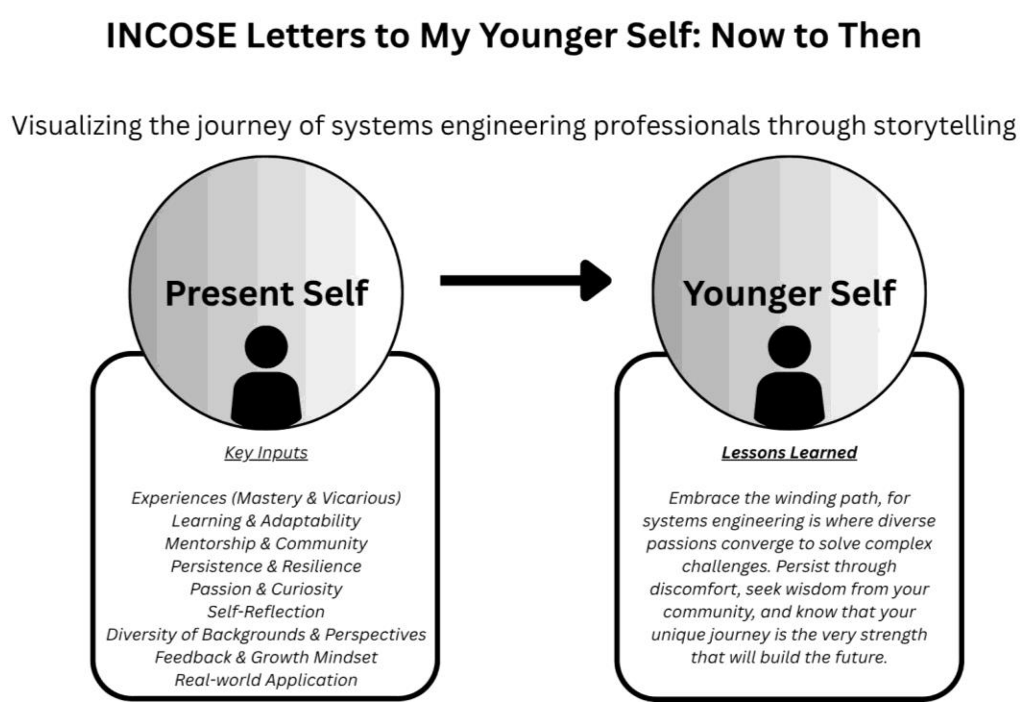

Figure 1. INCOSE EWLSE LTMYS From Now to Then

To illustrate the rich diversity of backgrounds and experiences contributing to the LTMYS Volume 1, Table 1 provides a sample of featured authors, their original disciplines, and key themes from their letters. This diversity is crucial for providing relatable role models to a broad audience of aspiring STEAM professionals.

Table 1. **Sample of Contributors to INCOSE LTMYS Volume 1**

Author Name	Country/Region	Original Discipline/Background	Key Insight/Theme
Virginia Aguilar	USA	Chemistry	Solving complex engineering problems with diverse perspectives; "Ah-Ha moments" from everyday observations.
Eileen Arnold	USA	Music, Geography	Discovering systems engineering as a transdisciplinary way of thinking; connecting diverse academic pursuits to systems thinking abilities.
Heidi Davidz	USA	Engineering Management	Importance of professional societies (INCOSE) as a "second family" for continuous support and professional development.
Stueti Gupta	India/USA	Engineering	Embracing adaptability and change; being "uncomfortable with comfort zones" to navigate evolving business landscapes.
Federica Robinson-Bryant	USA	Industrial Engineering	Resilience and persistence as a Black woman in engineering; importance of mentors and pushing through perceived limits.
Randy Iliff	USA	Systems Engineering	Trusting intuition and clarifying definitions in systems engineering; practical guidance for navigating the profession.

Roger McCowan	Australia	Engineering	Emphasizing continuous learning and the evolving nature of systems engineering; framing challenges as opportunities for growth.
Alice Squires	USA	Electrical Engineering	Making one's place in the world; driving change through systems thinking; importance of long-term vision and customer relationships.
Celia Tseng	Taiwan/USA	Biomedical Engineering	Global opportunities in systems engineering; applying systems engineering to life-saving technologies from an immigrant's perspective.

The LTMYS initiative exemplifies effective knowledge transfer and career inspiration, as seasoned professionals impart hard-won wisdom to aspiring individuals within the systems engineering field. Authors like Virginia Aguilar, in her letter, share a pivotal "Ah-Ha moment" where an everyday observation (oil on wax paper while baking cookies) solved a complex engineering problem, illustrating the value of diverse perspectives and unconventional thinking in systems engineering. This anecdote serves as a concrete example of vicarious mastery, showing young readers how real-world problems can be approached creatively. Eileen Arnold's letter, "A Journey of Passion," highlights how she "discovered in the mid-1990's her passion had a name - systems engineering," a transdisciplinary way of thinking that resonated with her innate systems thinking abilities cultivated through diverse academic pursuits like music and geography. Her journey underscores that systems engineering is not limited to a single academic path but embraces a broad spectrum of talents. Heidi Davidz emphasizes the importance of professional societies like INCOSE as a "second family" for continuous support and professional development, underscoring the community aspect of career inspiration and the value of verbal persuasion through peer support.

These narratives serve as a potent tool for career inspiration, demystifying the profession and making it more accessible. Stueti Gupta's letter, "Be Uncomfortable with Comfort Zones," encourages adaptability and embracing change, traits she attributes to her diverse upbringing and which are crucial for navigating evolving business landscapes. This provides a powerful message about persistence and resilience in a dynamic field. Federica Robinson-Bryant's "A Testament to Persist" powerfully addresses the challenges of being a Black woman in engineering, emphasizing resilience, the importance of mentors, and the need to "push through" artificial limits, directly contributing to diversity and inclusion efforts within STEM by providing a relatable and empowering role model. Alice Squires' "Making Your Place in the World" shares that challenging oneself allows you look back and see difficulties as stepping stones, and that a systems view is contagious and provides a framework to help others. Celia Tseng's "An Immigrant's Perspective" showcases how her trans-Pacific move opened unexpected opportunities, leading her to apply systems engineering to life-saving technologies, demonstrating the global and impactful nature of the field. By presenting varied personal journeys, LTMYS effectively inspires new generations to consider and pursue specific career paths in systems engineering, fostering a more diverse and engaged talent pipeline. The collective wisdom within these letters acts as a powerful form of professional development, offering insights into navigating challenges, identifying opportunities, and fostering a growth mindset.

IV. EWLSE's "Letters to My Younger Self" Initiative: Data and Analysis

Our organization, through its "Letters to My Younger Self" (LTMYS) initiative, has actively championed the power of personal narratives to inspire and guide aspiring systems engineers. The project involves soliciting authentic letters from a diverse array of systems engineering professionals, encompassing various career stages, backgrounds, and geographical locations. These letters, compiled into volumes, aim to provide a realistic yet encouraging glimpse into the systems engineering profession, addressing themes such as career navigation, overcoming challenges, mentorship, and the pervasive nature of systems thinking. The primary target audience for these contributions is high school students and young adults contemplating their future career paths, as well as those already embarking on their STEM journeys.

While specific quantitative data on readership (e.g., exact download numbers or views across all distribution channels) for Volume 1 is continuously being aggregated, initial metrics indicate significant visibility and reach. The publication has been strategically distributed through various channels, including presentations at conferences like the SySTEAM mini-conference, panels at events such as the Asia-Oceania Systems Engineering Conference (AOSEC), and promotional advertisements in professional newsletters. This multi-pronged approach has ensured broad dissemination to both academic and professional communities, as well as directly to educational institutions and youth programs. This widespread distribution strategy is crucial for maximizing the impact of the narratives.

Qualitative feedback from participants and readership engagement analysis reveals compelling evidence of the initiative's ability to inspire young people, bolster their self-belief, and provide vicarious mastery experiences. Testimonials highlight how readers resonate with the personal struggles and triumphs shared by the authors, finding validation in their own uncertainties and motivation in the demonstrated resilience.

For instance, the experiences detailed by authors like Randy Iliff, who advises his younger self to "trust your gut" and "confirm what someone means when they say 'Systems Engineering'," offer practical guidance that builds confidence and clarifies the often-ambiguous nature of the profession. This direct, personal advice acts as a powerful form of verbal persuasion, reinforcing the idea that systems engineering is a learnable and navigable field. Roger McCowan's letter, which emphasizes continuous learning and the evolving nature of systems engineering, encourages persistence by framing challenges as opportunities for growth, fostering a growth mindset essential for long-term engagement. These narratives serve as powerful verbal persuasion, directly contributing to the development of self-efficacy by showcasing that complex careers are navigable and rewarding. The emotional connection forged through these stories enhances the overall engagement and persistence of young readers.

Analysis of Volume 1 has illuminated several strengths. The diversity of authors, representing various disciplines (e.g., chemistry, industrial psychology, electrical engineering) who ultimately found their home in systems engineering, effectively demonstrates the interdisciplinary nature of the field. This broad appeal helps to break down preconceived notions of what an "engineer" looks like or does, broadening the potential appeal of the profession. The candid sharing of personal struggles, such as those articulated by Federica Robinson-Bryant regarding navigating a male-dominated field as a Black woman, fosters a sense of authenticity and relatability, making the advice more impactful and promoting inclusion. These personal accounts provide a realistic, yet inspiring, view of the profession, contrasting with often idealized or abstract portrayals.

However, lessons learned from Volume 1 also point to areas for improvement, particularly concerning distribution and targeted promotion. While general dissemination has been effective, there is an opportunity to enhance direct engagement with specific demographic groups and educational settings. For Volume 2, strategies will be optimized to maximize its reach and impact within the target demographic. This includes more targeted outreach to high schools and community organizations, exploring new digital platforms for accessibility, and potentially developing supplementary educational materials that accompany the letters. The insights gained from Volume 1 are instrumental in refining these strategies, ensuring that Volume 2 not only compiles more inspiring narratives but also reaches those who can benefit most from its message, thereby strengthening the STEAM pipeline. The goal is to create a sustained and expanding impact, consistently providing fresh perspectives and guidance to emerging talent.

V. Practical Tips and Actionable Suggestions for Integrating LTMYS

Leveraging the inherent power of personal narratives through the "Letters to My Younger Self" (LTMYS) framework serves as a vital intervention to strengthen the STEAM pipeline by nurturing the foundational elements of self-efficacy and sustained engagement. To maximize the impact of this approach, educators, mentors, and organizational leaders can effectively integrate LTMYS into their programs through various practical and actionable strategies. These suggestions are designed to empower participants to actively utilize these powerful narratives to motivate and guide the next generation of STEAM innovators.

1. Classroom Discussions and Curriculum Integration:

- **Guided Reading Sessions:** Facilitate classroom discussions around selected LTMYS letters. Provide students with guiding questions that encourage critical thinking about the author's journey, challenges, and advice. For example: "What was a key turning point in this engineer's career?" or "How did their early experiences shape their path into systems engineering?"
- **Thematic Units:** Integrate LTMYS letters into existing STEAM curriculum units. If teaching about problem-solving, select letters that highlight iterative design or overcoming technical hurdles. If discussing ethics in engineering, choose narratives that touch upon professional responsibility.
- **"Dear Younger Self" Reflection Activity:** Encourage students to write their own "letters to their younger selves" (or even "letters to their future selves" from their current perspective, focusing on their aspirations and the steps they imagine taking to achieve them). This fosters self-reflection, goal-setting, and can help students articulate their own emerging STEAM identities.
- **Systems Thinking Spotlights:** Use specific examples from the letters to illustrate fundamental systems engineering concepts in a relatable context. For instance, an author describing how different parts of a project had to work together can be used to explain "interconnectedness" or "system boundaries."

2. Mentorship Pairings and Role Modeling:

- **LTMYS as a Conversation Starter:** For formal or informal mentorship programs, provide mentors and mentees with relevant LTMYS letters to read and discuss. This offers a shared context and a natural starting point for conversations about career paths, challenges, and personal growth.
- **"Meet the Author" Sessions:** Organize virtual or in-person sessions where students can interact directly with LTMYS authors. This humanizes the profession further, allowing students and young adults to ask questions and gain deeper insights into the authors' experiences.

- **Peer Mentorship:** Encourage older students or young adults who have read LTMYS to share their reflections and insights with younger students, fostering a cascading mentorship effect within schools, outreach organizations, and businesses.
- **Author-Created Video Snapshots:** Leverage short video clips from authors to provide dynamic, personal insights and quick motivational messages, enhancing engagement and accessibility for readers.

3. Organizational and Outreach Strategies:

- **Targeted Distribution:** Beyond general publication, actively distribute LTMYS volumes to high school counselors, STEM club advisors, community youth centers, and university career services. Provide accompanying materials that explain the purpose and benefits of the letters.
- **Digital Accessibility:** Ensure LTMYS volumes are easily accessible online through various platforms (e.g., organizational websites, educational portals, e-book platforms). Consider creating audio versions or interactive digital experiences to enhance engagement.
- **Promotional Campaigns:** Develop consistent promotional campaigns through social media, educational newsletters, and partnerships with youth-focused organizations. Highlight compelling excerpts or author profiles to pique interest.
- **Call for Letters Workshops:** Host workshops for experienced professionals interested in contributing to future LTMYS volumes. Provide guidance on effective storytelling and how to craft impactful messages for a young audience.
- **Feedback Loops:** Establish mechanisms for collecting feedback from young readers (e.g., surveys, focus groups) to understand which aspects of the letters resonate most and to inform the content and distribution strategies for future volumes. This ensures the initiative remains responsive to the needs and interests of its target demographic.

By actively implementing these strategies, organizations and educators can transform the passive act of reading into an active, engaging, and transformative learning experience, truly empowering the next generation of STEAM innovators.

VI. Conclusion

The profound impact of storytelling, particularly through the "Letters to My Younger Self" (LTMYS) framework, offers a vital intervention for strengthening the STEAM pipeline. By leveraging the inherent power of personal narratives, this initiative effectively cultivates self-efficacy, persistence, and interest in STEAM disciplines among high school students and young adults. LTMYS has demonstrated its ability to inspire through vicarious experiences and verbal persuasion, demystifying complex careers and providing relatable role models. The authentic voices and diverse journeys shared within LTMYS provide a tangible roadmap for navigating the complexities of STEAM careers, fostering a resilient and engaged talent pool essential for addressing the multifaceted challenges of our world. Continued investment in such narrative-based educational strategies, coupled with proactive integration into educational and mentorship programs, promises significant long-term benefits for individuals and the broader STEAM ecosystem.

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Letters To My Younger Self

Volume 1

Integrating Transdisciplinary Skills in the Science and Business Program

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Abstract

Systems engineering and systems thinking are topics that are rarely taught as a distinct course in undergraduate programs. While many undergraduate engineering students are exposed to these topics through their design and capstone courses, students in other disciplines are seldom provided such an opportunity. Yet, many professionals with background in science end up working on complex systems and projects that rely on systems thinking and engineering.

This paper reviews attempts made in 2023 and 2024 to introduce students in the Science and Business Program at the University of Waterloo to systems thinking and engineering, alongside other transdisciplinary skills. It covers two approaches to integrating these topics in the program. On the curricular side, the SCBUS 323 Technology Development course was redesigned to focus on introducing product design and development to science and business students. On the extra-curricular side, Innosolve was created as a student-led extracurricular group which provides opportunities for student teams to explore innovative solutions to todays technical and policy challenges. Lessons learned from these activities and future changes are discussed.

1. Introduction

Systems thinking is among the transdisciplinary skills that most university graduates can benefit from. While engineering students are exposed to these topics through their engineering design course, other programs rarely provide an opportunity for students to learn and apply skills in these areas. This is particularly important for science students, who may form integral parts of teams working on complex systems. The author's experience is a testament to this: while he worked on lunar rover missions or various space station programs, the work not only involved engineers but science teams designing instruments and mission scenarios. These individuals do not need to be experts in systems thinking, design thinking and similar skills, but they do need to understand these approaches and contribute to them.

Upon starting his position at the University of Waterloo, the author noticed a lack of focus on transdisciplinary skills such as design thinking, systems thinking and communication within the program. This major gap led to various attempts to address the issue which will be summarized in this paper. In particular, one of the courses in the program was redesigned as outlined in section 2 to focus on product design and development. In addition, a new extracurricular opportunity was introduced as outlined in section 3 which provided hands-on learning opportunities to students to develop these unique transdisciplinary skills.

2. Systems Thinking and Engineering in the Science and Business Curriculum

2.1 The Science and Business Program

The University of Waterloo is one of Canada's leading research universities. Unlike most universities in Canada, the University of Waterloo possesses a less traditional faculty structure owing to how it was founded [1], with activities organized in 6 faculties: Science, Environment, Engineering, Arts, Mathematics, and Health.

The University of Waterloo is known for its emphasis of cooperative education, and of innovation and entrepreneurship. Yet, where business education fits in its structure is not trivial as the university does not have a traditional business school. Over the years, a model was developed which is dubbed "X and Business" whereby students interested in business study a major (Science, Arts, Math, Environment) and business.

The first of such programs was Science and Business, first introduced in 1972 [2]. While the program structure has changed over the years, the philosophy of the program has stayed the same: expose science students to practical aspects of business and management to prepare them for roles that marry these two disciplines. This amalgamation of science and business has allowed students to explore diverse career paths, ranging from founding a quantum computing company, to becoming product managers, to exploring the fields of medicine and biology.

The program structure as of 2024 is summarized in Table 1. After completing a set of general first year courses (covering basic mathematics, science communication and basic science) students embark on a journey of completing a series of courses in science, alongside fundamental aspects of economics and business. The Science and Business Courses developed in-house by the program complements this journey by integrating business and science concepts and forms the spine of the program.

Th program design is somewhat similar to the approach taken in other applied programs. For example, first year engineering students take a similar set of courses in BC [3]. After a common first year, many engineering programs approach their engineering design courses like the SCBUS courses as a connective tissue [4, 5]. However, while engineering programs have much more standardized content in their curriculum owing to the regulated nature of engineering, the Science and Business Program had a freer structure relying on the experiences of instructors to inform curriculum content. This is a shortcoming of the program, leading to a need to standardize the integration elements of the program which will be discussed in the next subsection.

Table 1. Structure of the University of Waterloo Science and Business Program as of 2024 [6].

	Year 1	Year 2	Year 3	Year 4
Integration	SCBUS 123: Workshop 1	SCBUS 223: Workshop 2	SCBUS 323: Technology Development	SCBUS 423: Strategy
	SCBUS 122: Management	SCBUS 225: Organizational Behaviour		
Business and Economics	Intro to Business	Microeconomics	Accounting	
		Macroeconomics	Business Finance	
		Microeconomic Theory	Business Law	
Science	Gen Chem 1 and 2 with labs	2 x 200-level science courses	1 x 200-level science courses	1 x 300-level science courses
	2 x First year Biology, physics or earth	A science course or a program elective	3 x 300-level science courses	5 x 400-level science courses
Math and Computing	Calculus 1 & 2	Intro to computing	Statistics	
Other	Communication	Creativity and Entrepreneurship		2 x program electives
				1 x elective

The program is designed with flexibility in mind. Students can make the following choices:

- **Specialization:** The students may take this program unspecialized (which is the layout shown in Table 1) or with specialization in Biology, Biochemistry or Biotechnology. Additional specializations in Physics, Chemistry and Earth Sciences used to exist until 2018, but were discontinued due to smaller number of students.
- **Cooperative Education:** Students may complete the program with a coop. This would entail completing 4-5 work terms in addition to their studies and would extend their studies by an additional year. The majority of students complete this program with a coop.

- **Program Electives:** Students may delve into particular areas of business or professional skills using program electives. Originally, there were only 11 program electives listed; however, through a redesign in 2024 the list of program electives was expanded to over 100+ courses already offered by various departments in the following categories:
    - Computing and Data Science
    - Environment, Sustainability and Ethics
    - Finance and Economics
    - Innovation and Entrepreneurship
    - International Business, Economic Development, Governance and Public Policy
    - Management and Business Consulting
    - Marketing and Communication
    - Organizational Behaviour and Human Resources
    - Socioeconomic Impact of Science and Technology
    - Other Business Focused Courses

  Currently students take only 3 program electives during their studied. The long-term goal for the program is to reevaluate the existing courses (both science and business) to explore whether the number of program electives could be increased to allow students to further tailor their studies to their interests and employer needs.

2.2 Transdisciplinary Studies in Science and Business: the SCBUS Spine

As mentioned in the previous section, a major focus of the program is to allow students to gain practical skills in science and business. The SCBUS courses form a backbone/spine of the program. While the program does not control the syllabus of courses offered through other departments, it does have full control on the Science and Business courses developed in house.

Figure 1 summarizes the SCBUS courses currently offered. These courses are designed with 5 criteria in mind:

- **Participatory and Active Learning:** While the courses do involve some lectures, they emphasize active learning through in-class activities and in class participation.
- **Team based:** These courses are the only opportunity for Science and Business students to work together. As such, the courses are designed to require work in teams.
- **Focus on applied skills:** The SCBUS courses focus on practical aspects of the topics involved and integrate an element of applied science and business into the program.
- **Hands-on courses with project- or case-based design focus on integrating knowledge:** The courses are designed to include hands-on elements requiring students to work in teams and achieve mastery learning through creation or evaluation (particularly in 300+ courses).
- **No formal final examination:** SCBUS courses rely on team projects as the main means of assessment. While there may be smaller quizzes, the courses do not include a final exam.

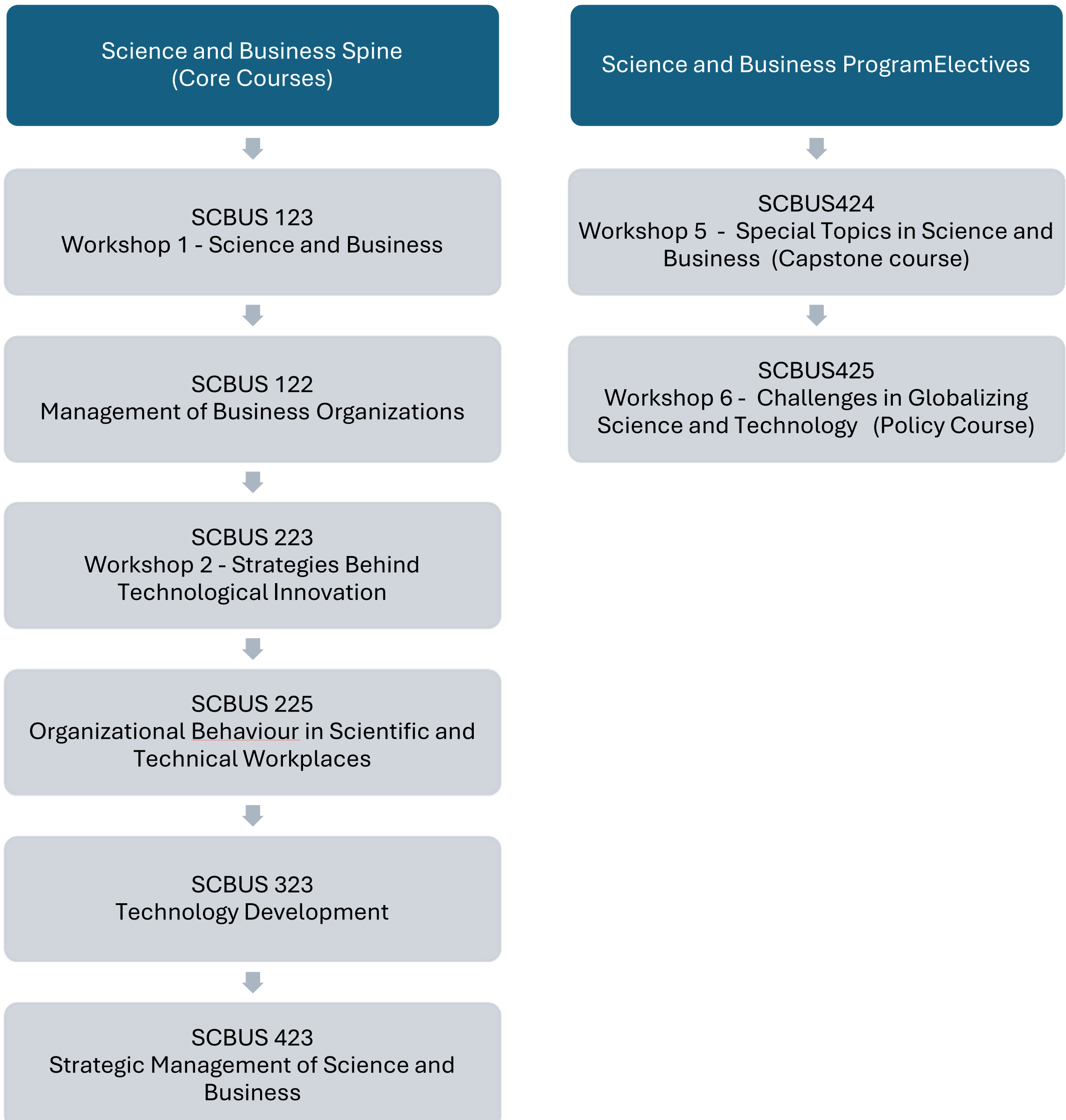

Figure 1: Science and Business Spine on offer in 2024 [6].

In a curriculum review in 2024, several gaps were identified in the existing program and its alignment with industry needs and student outcomes. These led to the following changes in the content of the courses:

- SCBUS 122 shifted from an introductory course in management to a course covering working in teams (20%), project management (40%) and topics in general management (40%)
- SCBUS 225 now includes business ethics, as the topic was not directly covered elsewhere.
- SCBUS 323 was redesigned to focus on product development.

Thes changes fill in the gaps in the existing curriculum, while emphasizing transdisciplinary skills such as project management, product development, teamwork and business ethics.

2.3 SCBUS 323: A Curricular Case in Systems Thinking and

The University of Waterloo Academic Calendar describes the course as [6]:

> A senior honours project focusing on technology innovation, assessment of the current utility of a technology, scale-up of the technology, projected return on investment and hurdles (production, regulatory, market competition, intellectual property protection). The major class project focuses on the development of a business plan for a product that could be commercialized. Applications, implications, cost benefit analysis, feasibility, etc. are included.

This description is very broad and can be interpreted in many ways. Yet, traditionally this course focused on business plan development, a skill that did not align well with interest in industry and career trajectory of our students. Our discussions with industry highlighted the need for innovative thinkers who can provide business analysis and kick start new initiatives using lean methodologies in agile environments.

Taking into account these trends, and the fact that our program did not cover any topic in product design and development, the course was redesigned to focus on developing the concept, mock-up and business model for a technology-enabled product. This zooming onto the early stages of developing a product (start-up with some consideration of scale-up and growth) allowed the course to be taught in a discipline unspecific manner.

Figure 2 highlights the life cycle envisioned for produce design and development within the course. By the end of this course, students were expected to be able to:

1. **Synthesize** trends in different industries, markets and areas of technology
2. **Formulate** a specific technical problem that can be solved based on the synthesis
3. **Plan** a product development cycle to develop and prototype a technology-based solution
4. **Design** a technical solution and business model that could be used to benefit from the business opportunity
5. **Prototype** the concepts relevant to the proposed technical solution and business model to demonstrate their feasibility, and product-market fit
6. **Pitch** the technology-enabled product to various stakeholders to persuade a funder to invest in your product, and entice users to use the product

Learning outcomes 2, 3 and 4 particularly cover topics from systems thinking, systems engineering and design thinking.

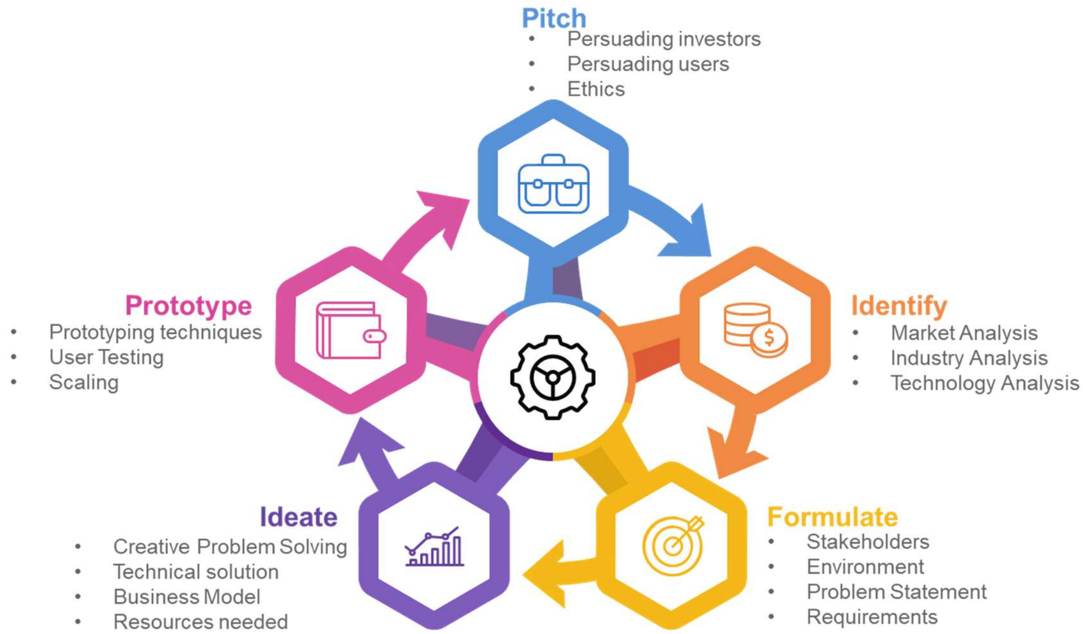

Figure 2. Concept behind the redesigned SCBUS 323.

This design was based on the notion that scientists are usually integrated into a product design team and need to know how these teams (comprised of professionals with backgrounds in engineering, marketing, arts, business) operate. Moreover, our students had ended up becoming product managers or founders, both cases where product design skills are important.

Figure 3 summarizes the knowledge areas covered and integrated by the course. Many of these topics were already covered in other courses in the SCBUS spine, with topics in bold being a focus of lectured in SCBUS 323. Students were also allowed to take two lectures off for a student-led learning opportunity, where they completed a learning activity related to their project proposed by themselves instead of the learning activities planned for class.

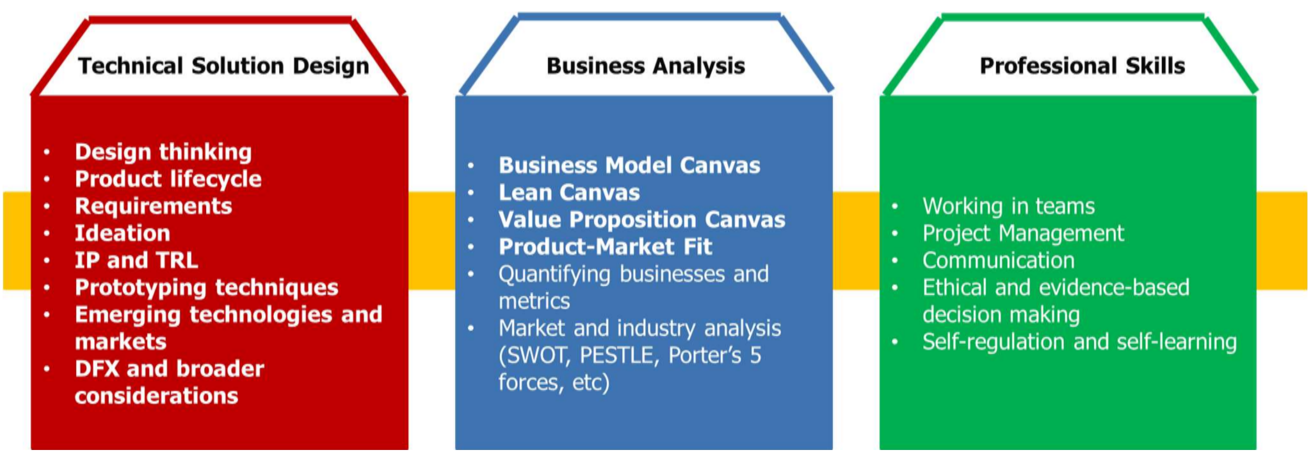

Figure 3. Knowledge areas covered by SCBUS 323 (the SCBUS utility belt).

Of particular interest to the readers would be the integration of elements of systems thinking and engineering in this course. The course presents the system life cycle and product life cycle to students for the first time in the program and focuses several lectures on problem formulation and solution development: taking stakeholder interest and operational environment in mind to define a problem statement, translate it to product requirements and user stories, and analysing alternative solutions using design thinking.

Figure 4 summarizes the student journey in this course. Originally the course had 9 deliverables during the 13-week semester; students found spending most of their time preparing documents. In the redesigned course, students complete 2 assignments and 2 presentations related to their product design. After proposing their idea, they take part in 4 informal progress meetings which replace many of the deliverables expected in previous iterations of the course:

- Project Kick-off Meeting
- Conceptual Design Review Meeting
- Business Model Description Review Meeting
- Final Design and Prototype Review Meeting

These meetings only required the submission of an ungraded 2-page progress summary, reducing the burden on students. A third assignment (not listed in the figure) focused on them reflecting on their experience and challenges with product development or working in their team.

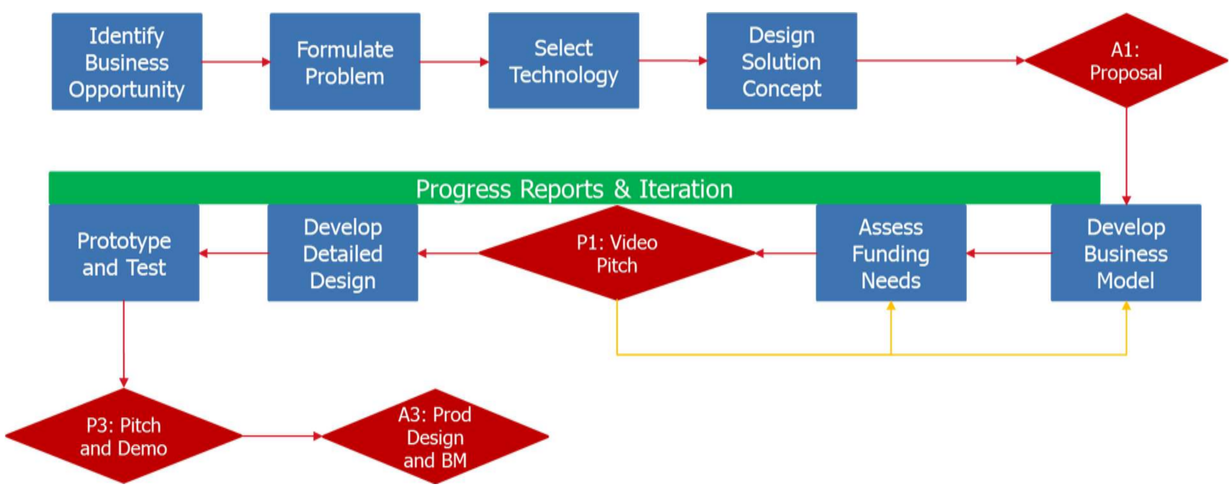

Figure 4. Student journey in the course.

The course culminated in the SCBUS 323 Spotlight event, where student teams presented their product concept and prototype demos at a public event organized by the program. Several guest judges assessed their work and provided feedback to groups so they could finalize their final design report. In addition, students were given tokens to use to invest in each other's products, adding a layer of gamification to the experience.

This new design was implemented in Fall 2024. It led to a 20% increase in student satisfaction with the course, compared to the version delivered in Fall 2023. Despite this increased satisfaction, several issues were identified:

- **Insight vs showing a tool:** This is a common issue faced by students, whereby students think that by using a tool shown in class they should achieve the highest grade. Yet, what is important in the real world is not using tools, but the insights you extract from the tool. Prioritizing the communication of the insight vs the tool is a major emphasis of the course.
- **Selecting the right tool and form of communication:** Another major challenge for students was selecting the right tool from the range of tools available to them. And using the right mode to communicate information. In many cases students would approach the author with a complaint that the page limit does not allow them to use all the tools; yet the point was to use the right tool, and to use language to communicate the insights from the tool properly.
- **Course duration:** This course was implemented in a single semester of 13 weeks. While this amount of time is enough to cover all content, it is not enough for a "senior honours project" as described in the original description. To allow students to really explore problem formulation and design space exploration properly, the course should be offered as a two-semester experience. This will also allow the addition of tutorial sessions in addition to the lectures specially during the second half of the course, where student teams can work together supervised by the instructor and can ask the instruction team for support or hold their progress report meetings.
- **Order in the SCBUS spine sequence:** As outlined earlier, students taking this course have not taken their strategy course yet. This is a major shortcoming, as strategic analysis is a relevant skill for product development. Considering the language used in describing this course in the calendar, this course may be better suited as the final course in the series.
- **Student motivation:** A few students noted that while they like the topics covered, they do not see themselves working on product design because their aim is to work in sales or marketing. As such, they find the team project unnecessary. This highlights the need to better communicate the importance of diverse skills in the design team, and the various career trajectories of graduates.
- **Lack of suitable resources:** While there are many books out there covering aspects of the topics covered in this course, there was no resource that covered all topics with an applied lens. This issue is addressed in the conclusion.

A few of these lessons learned led to proposals for curriculum changes for future program offerings.

3. Innosolve: An Extracurricular Case in Systems Thinking and Transdisciplinary Skills Integration

In addition to its curricular activities, the Science and Business Program at the University of Waterloo organizes various Extracurricular activities at program level to provide an opportunity for community building and skills development for our students. While students could take part in extracurriculars outside of the program, the need to provide opportunities in-house was key to address the unique needs of our students. Participating in extracurriculars is rewarded by the program, allowing students to gain professional development points towards their SCBUS courses.

As of September 2023, these activities consisted of 7 initiatives [7]:

- **Student-led activities:** These activities were managed directly by students, with some budget and advice provided by faculty and staff.
    - **Fusion Annual Conference and Case Competition:** A conference organized by students from the Science and Business program since 2004, and open to all undergraduate students. The conference includes keynote speakers and a case competition.
    - **Science & Business Students' Association (SBSA):** This association brings together students to create a close-knit community in which students can socialize and find opportunities for personal and professional growth.
    - **Science and Business Ambassador Team (SBAT):** A student-run organization is dedicated to supporting Science and Business students through the provision of information, resources, and mentorship.
- **Faculty and staff led**
    - **Founder's circle:** A mentorship program connecting Science and Business students with an interest in entrepreneurship with alumni and the broader Waterloo innovation ecosystem. Students can connect with each other and learn more about founding their own start-up or joining a team early in the business life cycle.
    - **MyBusiness:** A student career and personal development program providing one on one mentorship that helps students create a roadmap and an evolving guiding compass at their own pace. At the end of the exercise students develop a personalized career management plan, where there is time made for conversations on real life scenarios in relation to the content.
    - **Watsolve Consulting Group:** Founded in 2017, this multidisciplinary team of undergraduate Science and Business students provide pro-bono consulting services to science and technology-based businesses of all sizes
    - **SCBUS Mentorship Hub:** This hub powered by Ten Thousand Coffees builds strong relationships between students and alumni through one-on-one mentorship.

Each faculty and staff member in the program is linked with one of the extracurricular activities. As such, the author was asked to propose a new student-focused extracurricular opportunity. Analyzing the existing extracurriculars revealed the for more opportunities to upskill, the need to promote and support participation in external competitions, and the lack of project-based work on real-world problems.

Externally, there are many opportunities to explore and respond to challenges identified by external stakeholders, be it government, intergovernmental organizations, industry, and academia. In some cases, these opportunities take the form of competitions, while in other cases they form co-creation opportunities. Yet, there was no clear pathway for science and business students to engage with these challenges, unlike say students in engineering who benefit from structured opportunities through the likes of the Sedra Student Design Centre. Moreover, students may need workshops that bridge the gaps in their skills relevant to these opportunities.

Taking into account this internal and external analysis, Innosolve was created in October 2023 as a space for exploring innovative solutions to our society's complex technical and policy challenges. Student joining Innosolve would:

- Solve open-ended technical and policy problems
- Build prototypes to showcase solution
- Create a business model to enable the solution or policy recommendation
- Present their ideas at national and international competitions
- Develop technical and transdisciplinary skills

Innosolve kicked off in January 2024. The original concept was to form several projects teams, an events team and several competition teams. However, this structure evolved over time, as interest in competitions wined down and interest in projects grew. By March 2025, Innosolve outcomes included:

- The Innosolve student logo competition held in 2024, with the logo coming online in September 2024.
- A co-creation team was created, initially focused on Early Warning System for Wildfires as defined by the author. The team was mentored by the author and performed stakeholder engagement with the Canadian Government and Nonprofits focused on wildfires. The team pivoted to wildfire risk assessment using real-time data and machine learning, forming Firebird Labs and presenting their initial model at the Socratica Symposium 2025 in Waterloo.
- As a result of the needs of the co-creation team, Innosolve held a 3-hour Python crash course for the Science and Business program.
- Innosolve held its first hackathon titled Blitz Hack: Defining next generation Space Payloads in Fall 2024.
- As a result of the hackathon, a team of students was formed focused on Building a comprehensive database of space radiation shielding materials to enable better decision-making for space missions. This team was the first time Innosolve went beyond Science and Business, with students from mathematics and physics joining the team.

- Two more co-creation teams were also created in Fall 2024: the student grocery price comparison app, and the biotechnology project.
- Competitions and external opportunities were promoted to the SCBUS program, with Innosolve supporting creation of resource pages outlining external opportunities for students.

Systems thinking and engineering, and other transdisciplinary skills were a cornerstone of what was practiced by Innosolve participants, and key in the success of its initiatives. While students learned about topics like project management, design thinking or systems thinking in class, their practical application to a real-world problem of interest to them was a new and unique experience.

Four key features helped Innosolve succeed:

- **Mentorship:** Innosolve relied in hands-on mentorship by the author as a faculty member supervising the group. The author attended all meetings, especially early in each team's journey as they were navigated how to manage work, how to identify opportunities. As teams matured, the need for mentorship decreased. Based on the authors conversation with other student groups on campus, this hands-on involvement of faculty is uncommon, understandably so as at many other student teams have a very focused scope and as such do not require as much support from faculty members.
- **External Experts:** Another key need was linking teams with external experts who could point them to the right resources. Obviously, the author is not an expert in every topic; in fact, he may be better described as a jack of al trades and master of none. As such, leveraging both the author's network and university resources (such as our incubator) were key to ensure students gain access to the right expertise to better assess their ideas.
- **Tailoring:** In many cases, creating the right process for the various groups, taking into account the unique scope, student interest and their personality was key. In other word, one size does not fit all, and adaptability and tailoring were key, a lessons students learned by heart.
- **Sustainability:** While the author did mentor most groups personally, the aim was to create a sustainable model long term. The author left the University of Waterloo in March 2025, with Innosolve losing its mentor. Despite that, the team has persevered and continued to operate. Part of this has to do with training students in what the author did as a mentor, with those interested in managing the group shadowing the mentorship of different groups.

4. Conclusion and Lessons Learned

This paper presented curricular and extracurricular examples of integrating systems thinking and other transdisciplinary skills in a unique program focused on science and business. These skills transcend our usual disciplines and are needed by anyone thinking of interacting with technology, be it on the technical, business or policy side. Project-based hands-on integration is the only way to gain these skills in a manner applicable to real-world work situations.

One of the major findings of the author in this process was the lack of resources that are designed to teach these transdisciplinary skills (systems thinking, design thinking, opportunity identification, etc) in an integrated manner. This is not a major challenge for extracurriculars, but in curricular cases the author had to rely on various articles and chapters of books to cover these topics which at times students found too demanding. To address this issue, the author is currently developing "Product Design and Development for Scientists and Engineers" [8], an Open Educational Resource overs technical aspects of product design, business aspects of developing a product, communication, project management and team work. This resource will be available in 2026.

Acknowledgement

This paper is based on the author's experiences as an Assistant Professor – Teaching Stream at the University of Waterloo.

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Safety Third Follow-up: Updating the Project-Based Approach to Systems Engineering Education

Chris Brown, Ph.D.

Alabama School of Cyber Technology and Engineering

Introduction

The Alabama School of Cyber Technology and Engineering (ASCTE) is a statewide residential magnet school located in Huntsville, Alabama. The school is the first in the United States focused on cybersecurity and engineering, and every student is required to take cybersecurity and engineering courses during each term. Additionally, during their senior year, each student completes a capstone project and an internship with a local industry partner. This layout provides an excellent opportunity to test methods of systems engineering instruction at the high school level.

Safety Third: A Case Study for a Project-Based Approach to Systems Engineering Education (Brown, 2023) was presented in a poster session at the 2023 INCOSE SySTEAM mini-conference. Since then, two more classes of ASCTE students have conducted large projects using the framework presented. This paper reflects on the execution of the framework and updates to the nature of the project during that time. Additionally, at the 2023 conference, the question was posed as to whether one could demonstrate the efficacy of the teaching method. Initial survey-based research was conducted, and preliminary results will be briefly discussed.

The Project-Based Approach to Systems Engineering Education

The project-based approach takes advantage of the ASCTE program, in which students have dedicated engineering courses throughout their high school career. There are a number of excellent project-based engineering curricula in the United States, however, these are typically geared toward short-term projects conducted by individuals or small groups. These work well for teaching disciplines such as mechanical or electrical engineering, however, a larger project with ten or more students is better suited to demonstration of systems engineering and project management concepts. The dedicated engineering classes at ASCTE create an ideal environment, however, the approach could be replicated in other programs.

The approach, as described at the 2023 INCOSE SySTEAM Conference, engages students in an eight-week project involving numerous systems and project disciplines. Students meet four times per week in engineering class, plus some out-of-class time. The duration of the project can vary, but it is not recommended to take less than six weeks. In the original ASCTE project, students created a small car propelled by model rocket engines, with a microcontroller for ignition and data collection. The described framework is project agnostic, but any project should be large enough to require a degree of interface management and integration of multiple components of different types.

A key component of the framework is that students are assigned roles based on team needs and their own desires. While every student receives the same basic classroom instruction, they each have preferred specialties. A Project Manager was selected from volunteers in each class. They then drafted classmates until there were twelve to fifteen members on each team. With teams selected, roles were then assigned within the teams. These roles included requirements manager, master scheduler, cost estimator, risk manager, cybersecurity manager, lead programmer, etc. A breadth of technical and project management roles were filled by members of the teams.

The framework included twelve steps: 1.) Assign roles, 2.) Requirements definition, 3.) Analysis of Alternatives, 4.) Project planning, 5.) Initial Design, 6.) Modelling and Simulation, 7.) Final design, 8.) Fabrication, 9.) Earned Value, 10.) Risk, Quality, and Safety, 11.) Test and evaluation, and 12.) Analysis. During the eight week term of the project, teams progressed through these stages. These represented the engineering design process and allowed students to experience many of the sub-disciplines of systems engineering and project management. They engaged in systems thinking, considered aspects of engineering and product design not typically covered at the high school level, and demonstrated proficiency in a variety of subjects.

The ability of students to choose roles of greater interest for themselves was critical to maintaining engagement and excitement throughout the project. This version of the project was also framed as a competition, in which teams tried to achieve goals such as greatest distance traveled, and the competitive nature also maintained student excitement throughout the term. In short, this approach exposed students to much of the systems engineering world while maintaining enthusiasm.

Updates to the Project-Based Approach

Since the initial presentation in 2023, two more cohorts of ASCTE seniors have completed a course using the framework described. There have been a few notable changes during that time. First, the ASCTE Engineering Department adopted its own version of an engineering lifecycle, which may be seen in Figure 1. This was developed to present a more complete view of the engineering lifecycle, while using terminology simple enough to be meaningful to students beginning in ninth grade. This now provides the basis for most engineering instruction at ASCTE.

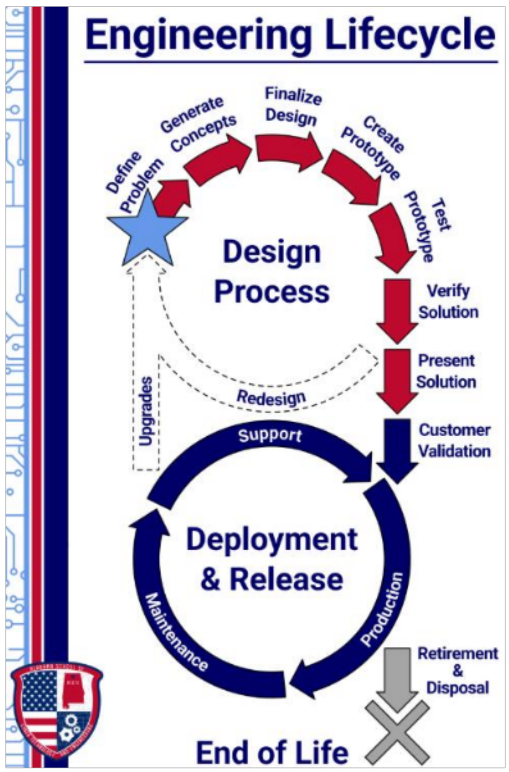

Figure 1: ASCTE Engineering Lifecycle

The original framework was described as project agnostic, and this has been demonstrated as the most recent project was completely different from the original presentation, while maintaining the key features of the process. In the latest project, students created a pumped-hydro electricity generation demonstrator. The materials were funded by a grant from the Tennessee Valley Authority, which uses the pumped-hydro concept at their Raccoon Mountain facility. Pumped-hydro generation involves first pumping water to an upper reservoir during low-demand hours. Then, at high-demand times, the water is allowed to flow downhill through turbines which generate electricity. In effect, the upper reservoir acts as a large battery. This is especially useful when other sustainable methods such as wind and solar generation are coupled with the pumped-hydro system. The demonstrator the students created used solar panels for part of the generation, and microcontrollers to operate relays, pumps, and solenoid valves for the pumped-hydro system. This project maintained all the key ingredients necessary to walk students through the systems engineering process.

A few changes to the framework and aspects of the project also took effect since the initial presentation. There was no longer a direct competition between the teams. Discussion with students and observation of teams revealed that the project was still very engaging, and the indirect competition inherent in teams trying to devise the most effective design or reach certain milestones first was more than enough to keep up the excitement. There was also greater emphasis on teamwork and collaboration. While these were always important, later groups were more strongly encouraged to make use of diverse viewpoints and to strive to work well together with everyone doing their part.

In the technical aspects of the project, there was greater emphasis on critical systems engineering functions like requirements definition and key project planning functions. The design and fabrication elements, while important, were emphasized less, given that the goal was to teach systems processes. Earned Value Management, while taught in the class materials, was emphasized less as students had found it difficult to apply to the project. Overall, the changes to the framework and its application were minor, and students have reported that the project approach described helped them learn effectively.

Student Survey Instrument: Preliminary Results

A question posed at the 2023 INCOSE SySTEAM Conference was concerned with how we can know that this approach has been effective. In an attempt to answer that question, an initial round of survey-based research has been conducted. It has been stated that the ASCTE program includes a capstone project and internship during the senior year. However, approximately one quarter of students begin the program as sophomores rather than freshmen, and these students have truncated final classes and a shortened internship. The truncated engineering class does not include the eight-week project or a prior four-week project. This presents a natural experiment to compare the majority group with the latter group after they complete internships.

The survey instrument included basic demographic information and questions related to the ASCTE coursework and internship, which have not been validated. It then included components of the validated Course Experience Questionnaire (Liu, 2017) and Work Experience Questionnaire (Luk, 2020). The CEQ questions were posed in context of the final engineering course at ASCTE, and the WEQ questions were posed in context of the internship at an industry partner. A total of 57 students completed the survey, with 41 coming from the majority full-program group and sixteen coming from the truncated group. All items used a five-point Likert-type scale, and simple two-sample t-tests were performed to compare the different groups. While additional years of surveys and more sophisticated analysis will be necessary to draw significant conclusions, the preliminary results contain some points of interest.

Students who completed the full engineering course with projects and the longer internship scored higher on almost all CEQ questions, with one being statistically significant: The course provided me with a broad overview of my field of knowledge. This is not surprising given they had an additional eighteen weeks of engineering class, including the eight-week project and a different four-week project. Interestingly, the group with a shorter course and internship scored higher on most WEQ items, with two related to goals and clarity of internship roles being statistically significant. This seems counterintuitive at a glance, however, these students went directly from class to internship with no break, and any uncertainties for the year's internships would have already been worked out by their peers in the full-internship group. An interesting note not directly related to the topic at hand is that female and minority students scored higher on WEQ items, expressing greater appreciation of their internship experiences. Again, these results are preliminary and must not be taken as significant or conclusive at this juncture.

Conclusion

The ASCTE engineering program provides an ideal space to demonstrate methods of systems engineering instruction. The framework first presented in 2023 has undergone minor changes and updates, however, it has shown to be effective with additional cohorts of students executing different types of projects. Additionally, preliminary survey results indicate that students engaged in the project-based framework report a greater understanding of the body of knowledge. Future work will continue to develop the framework and generate additional survey data with which to create a fuller picture of the efficacy of the approach.

Works Cited

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