**THEORY TO PRACTICE: SYNERGISING CREATIVE AND CRITICAL THINKING TO GUIDE FINAL YEAR PROJECTS THROUGH THE RAINBOW FRAMEWORK-**

**A STEM PERSPECTIVE**

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**Abstract**

**The fast changing, information driven economy demands the ability to synthesise diverse sources of knowledge to solve multifaceted real-world problems. Therefore, researchers have highlighted the need to inculcate creative and critical thinking skills and dispositions (CCTD) through intentional, and scalable educational efforts. To facilitate honing of CCTD in final year students about to enter the workforce, it is vital to equip lecturers in institutes of higher learning (IHLs) with necessary competencies and resources. The study distilled the theoretical understanding of CCTD to develop a framework (RAINBOW) of guiding questions to build CCTD. A qualitative research design was employed to understand the experiences of lecturers and students in final year projects (FYP) and seek feedback on proposed framework and interventions. Focus group discussions (FGDs) were conducted with lecturers and final year students from multiple disciplines including Engineering, Infocomm Technology, Health, Hospitality, and Management. Findings revealed challenges faced in FYP, the skills and dispositions required to do well, indicating a clear need for suggested interventions. Key FYP challenges articulated by students included not knowing where to start or what questions to ask, finding the appropriate resources, and adapting to unexpected problems. Salient FYP challenges faced by lecturers included meeting project expectations, guiding students on how to get started and go through the process leading to the final presentation. Both students and lecturers indicated thinking critically, communicating well, and developing creative solutions as top 3 skills required to do well in FYP, while resilience, ownership, and openness were listed as the top three dispositions. They reiterated the need for guidance and resources to help them prepare better for FYP. These needs were mapped with CCT processes to refine RAINBOW framework of guiding questions to help them recognise real issues, ask the right questions, interlink the information, envision the solutions, balance the implications, observe the changes, and widen the possibilities, through project work. Interventions recommended include RAINBOW based e-course and Communities of Practice (CoP) for staff, complemented with parallel e-course and sharing of past projects for students. The paper also covers limitations and implications for future research.**

**Keywords:** *Critical and Creative Thinking Skills, RAINBOW Framework, Final Year Projects, STEM*

**Introduction**

21st century workplaces are in a state of continuous innovation and in need of engineers with creative and critical thinking skills necessary to solve present and future challenges (Tucker, 2001; Twohill, 2012). These critical core skills are essential to manage challenging workplace projects, to unpack issues and to create novel and well-balanced solutions. Peterson et al. (1997) showed critical thinking as the most important element in medium to high complexity jobs which are defined as encompassing a wide array of tasks including decision-making, planning, negotiation as well as engineering, and problem-solving.

This challenging workspace regime places a demand on educational institutions to produce a workforce of independent thinkers, problem solvers, and decision makers (Silva, 2009). According to Soule and Warrick (2015), the 4Cs (critical thinking, communication, collaboration, and creativity) are the main skills that would complement core academic subject knowledge. The business need for innovation shows the importance of teaching undergraduate engineering students how to be better creative and critical thinkers. Unfortunately, the literature in this area suggests critical thinking stagnation and creative decline in undergraduate engineering students (Sola et al., 2017).

Evidence shows that teacher competencies, teaching instructions, and the learning environment directly influence students' creativity and higher-order reasoning (e.g., Ames & Archer, 1988; McKeachie, 1986; Ng & Smith, 2004; Nolen, 1988; Smith, 1977; Tan, 2004). Consequently, appropriate design and intentional integration of teacher competencies, teaching instructions, and the learning environment can foster students to be more creative problem solvers. To fulfil the mandate of guiding students effectively to think creatively and critically, the lecturers must be prepared first. They need to be skilled and familiar with the processes and knowledge of creative thinking, problem-solving and experiential methods, and the ability to use research to guide classroom practices (Houtz, 1992). To fill this gap, a seven-step framework of guiding questions was conceptualised, and corresponding curriculum interventions were proposed for the professional development of lecturers to prepare them to supervise students’ project work. Student development interventions were also suggested in parallel to prepare them for project work.

**Methods**

Qualitative research was employed to gather insights and seek feedback from key stakeholders. Two FGDs were conducted with experienced and novice lecturers from various disciplines (N=6 each). And 1 FGD was conducted with final year students (N=8) from various disciplines and levels of performance in FYPs, to understand their experiences and seek feedback on the conceptual framework and potential interventions. Qualitative data collected on experiences such as challenges and rewards, attitudes and skills, gaps and interventions was subjected to thematic coding. The findings were subsequently analysed to refine the conceptual framework of RAINBOW and recommend corresponding interventions.

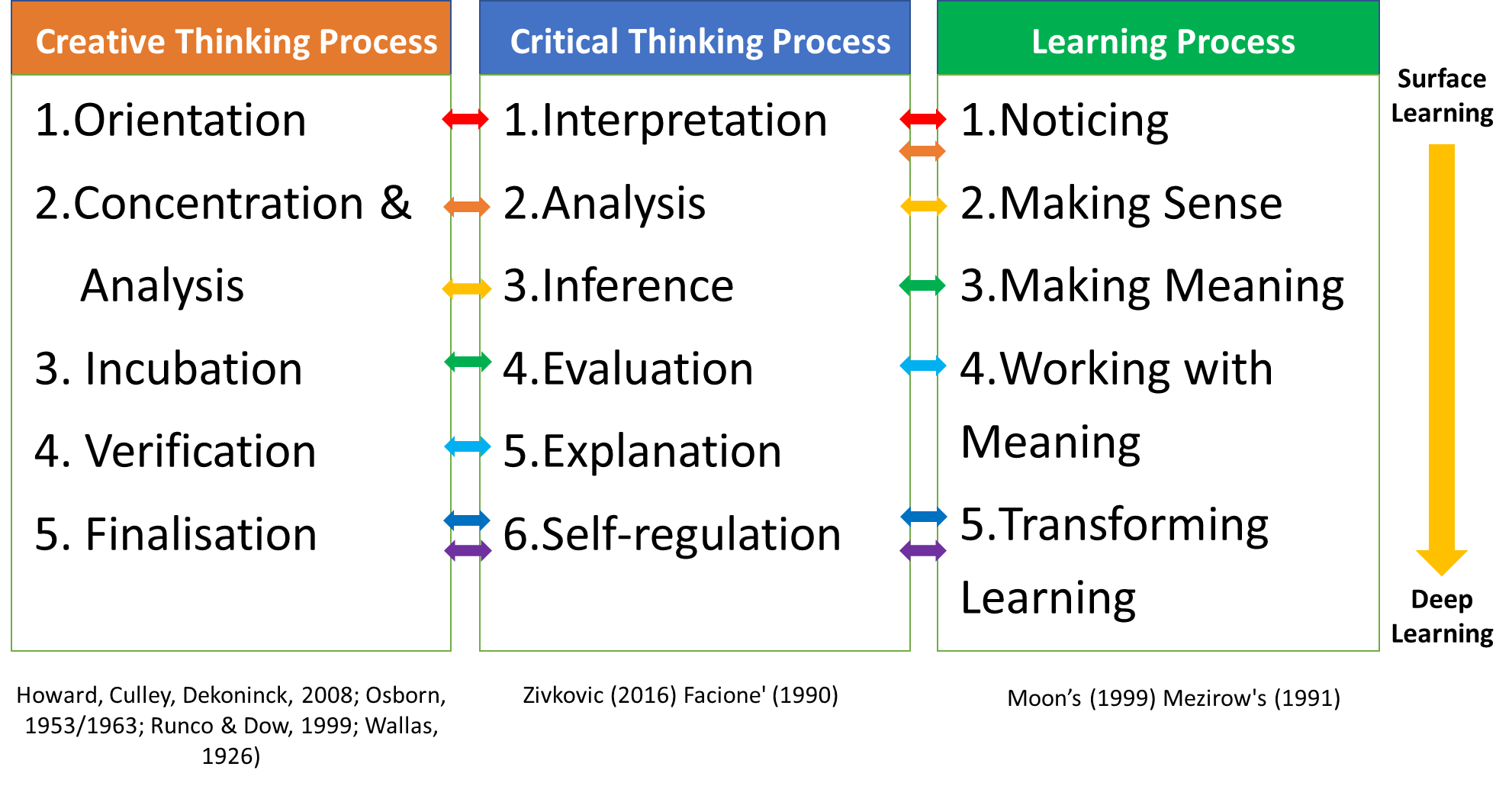
**Literature Review and Conceptual Development**

***Creative Thinking:***Itis the capacity to generate a variety of ideas, use ideas in unusual ways, and perceive patterns that are not obvious, to produce novel possibilities that have the potential to address an intention or objective (Ramalingam et al., 2020).

The creative thinking process comprises of several stages as described by various researchers (e.g., Howard et al., 2008; Osborn, 1963; Runco & Dow, 1999; Wallas, 1926). For this study, it has been identified as a five-stage activity: (1) The orientation stage is where the individual identifies the problem that must be solved (Osborn, 1963). Some activities include problem selection (Busse & Mansfield, 1980), problem finding (Runco & Dow, 1999), problem differentiation (Bruford, 2015), posing the problem and constructing a problem (Mumford et al., 1994).  (2) The concentration and analysis stage is where the individual focuses their attention on information or solutions deemed to be adequate and rejects the other solutions (Botella et al., 2011; Carson, 1999). (3) Accordingly, incubation occurs (Botella et al., 2011; Osborn, 1963; Runco & Dow, 1999) and is the time of solitude and relaxation where ideas association occur at a subconscious level (Carson, 1999). Ideation, with the generation of further ideas which are not necessarily judged nor assessed, surfaces as the main activity in this stage. The individual also experiences an illumination i.e., the emergence of an idea, or solution (Carson, 1999; Shaw, 1989; Wallas, 1926). (4) For the verification stage (Wallas, 1926), new ideas are tested and verified, leading to the elaboration of a solution and its production (Carson, 1999). Synthesis is evident in this stage, which consists of gathering ideas together and distinguishing relations between them. This work corresponds to developing and implementing ideas through a search for solutions (evaluation, selection, and redefinition) and then accepting this solution (promoting an idea, looking for its strengths and drawbacks). (5) The finalisation stage concludes refinement and adjustments (Botella et al., 2011; Cropley & Cropley, 2012).  The individual reflects and reassesses production and may choose to finish, elaborate, abandon, delay, store, or destroy it.

***Critical Thinking:*** Itcan be described as the metacognitive ability to ask critical questions, test assumptions, review evidence, consider new perspectives and explore decision-making alternatives (Miller et al., 2014). Good critical thinking can also be understood as a process of reflecting rationally and critically on one's assumptions and beliefs (Mezirow, 1991). In a nutshell, an ideal critical thinker possesses both analytical skills and appropriate dispositions (Gul et al., 2010; Perkins et al., 1993). Most of the literature focuses on the critical thinking skills and dispositions (e.g., Dewey, 1993; Ennis, 1985, 1996; Facione et al., 1994; Facione, 1990; Fisher & Scriven, 1997; Paul & Elder, 2006). Zivkovic (2016) advanced Facione' (1990) model to propose a possible six-step process: (1) The start of this process is signalled by the evidence of an ill-structured problem. The interpretation step requires identifying the problem and then defining what influenced this to occur. The formulation of the question in context, categorisation, decoding significance and clarifying meaning is vital at this stage. (2) The analysis step is to investigate the assumptions, examine ideas, opinions and arguments involved in the situation or problem. (3) Once the research is conducted, the inference step will take place to evaluate the information factually. The activities involved include recognising predispositions and weighing the information from all resources to reach a realistic and practical conclusion. One should also query evidence, conjecture alternatives, and conclude this step. (4) The evaluation step is to establish the significance of the conclusion and includes assessing claims and arguments, considering all points of view, and being open-minded, which is a good time to involve others in finding the best solution. (5) The explanation step involves communicating the findings and results, justifying the procedures, and presenting arguments. Failing to do so can cause much confusion. (6) The final step, self-regulation, suggests the need to reflect, question, confirm, validate, and connect the proposed solution to ensure a complete process and conclusion.

***Synergising Creative and Critical Thinking to Transform Learning:*** To transform thinking process, we must attempt to change a persons' thinking habits and patterns through noticing, making sense, finding meaning of the new idea, reflecting on their presuppositions resulting in a change of their thinking pattern (Mezirow, 1991). Figure 1 illustrates through colour-coded arrows how creative and critical thinking processes run parallel and could be mapped to the learning process to enhance learning. While creative thinking strengthens ideation, critical thinking provides reasoning, together they transform learning.

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**Figure 1. Synergising Creative and Critical Thinking to Transform Learning**

To enable students think creatively and critically and move beyond surface learning in FYP, a 7-step framework of guiding questions was developed. As illustrated in Figure 2 below, each question aimed to inculcate certain CCT skills and dispositions, to help students deliver the FYP outputs in a more systematic way.

Chart

Description automatically generated

**Figure 2. RAINBOW Framework**

**Results**

The FGD findings have been organised under three categories: Challenges and Rewards seen; Attitudes and Skills needed; Gaps and Interventions identified. Both the FGDs with lecturers and students indicated the need for suitable interventions to help them inculcate CCTD through FYPs.

***Challenges and Rewards:*** The biggest challenges cited by students in FYP included not knowing where to start, asking the right questions, finding the right resources, and adapting to curve balls, all of which require creative and critical thinking skills. A student shared during the FGD, *“We were lost, unsure of how, where to start, and what to ask”.* This anxiety mirrored in lecturers whose biggest challenge was meeting projects expectations by guiding students from beginning to the end. One of them shared the concern about *“How do we get started and guide students to learn, process data, and draw conclusions”.*

Students and lecturers also shared the perceived rewards from the FYP experience. While students cited gaining a sense of achievement and benefitting from the real-life experience, the lecturers appreciated the opportunity to help students grow and contribute to the industry through the FYP. A student stated *“(I feel) joyful to overcome challenge. (The FYP experience was) artistically fruitful”*, and a lecturer shared *“(It is) rewarding to go through the process to see students grow and create a product.”*

***Skills and Attitudes:*** During the FGDs, both students and lecturers indicated the need for skills to think critically, communicate well with various stakeholders and come out with creative solutions to meet client expectations. For example, students shared that *“We need to find our resources on how to make code better, through Googling & watching YouTube videos” and “Planning and infusing technology into the event itinerary was challenging. The challenge was what to include in the Virtual Reality with the aim of educating senior citizens. It challenged my creativity. I enjoyed it.”* Lecturers reiterated that students should *“be critical in reviewing ideas”, “know how to communicate with teammates”, and “know how solutions can be designed”.*

The discussions further highlighted resilience, ownership, and openness to be the top three dispositions required to do well in FYP. Students emphasised on the need to be resilient *“…keep bouncing back whenever you get knocked down …”; to take ownership “ “We are bound to face challenges, supervisor cannot spoon-feed us, need to do our own research”; and to be open to ideas, “Everybody has different ideas, (you) cannot just be set on you own idea, (but should) think about how the others’ ideas will help.”* Lecturers reaffirmed the need for *“Consistency”* and ownership as *“FYP is not a textbook. Students need to figure out the solutions… do research for insights…”, “deep dive and ask questions…”*

***Gaps and Interventions:*** Although students were taught a Critical Thinking and Problem-Solving module in year 1 but they may not recall the concepts sufficiently to apply them to project work in year 3. This is evident from the gaps highlighted by students during the FGD, including lack of preparedness, understanding, resources, ideas, and feedback. For instance, one of them shared, *“Searching for information on Google was frustrating at times” and “(I was the) only one giving ideas in the team.”* Students requested guidance from their supervisors, specifically on how to ask and answer questions, overcome crisis, interpret, and ideate. Another student mentioned, *“ask us questions that the assessor may ask, to prepare us (for the assessment)” and “teach us how to interpret articles”.*

The FGDs also showed that both lecturers and students were receptive to suggested interventions, including a RAINBOW based e-course and CoPs for lecturers and a parallel e-course with frequently asked questions (FAQs) and a sharing of past projects by seniors or through a discipline specific virtual gallery.

**Discussion**

The FGD revealed four key findings:

1. **Needs of Lecturers and Students** to adequately prepare them for FYP challenges. These needs could be shared with lecturers and students about to embark on this journey to prepare them mentally for the challenges ahead and ways to overcome them.
2. **Perceived Rewards of FYP** that make the experience worthwhile. These rewards could be highlighted to students and lecturers to generate their interest and commitment before they embark on their FYPs.
3. **Portfolio Development Opportunity** to build lecturers’ capability in helping students develop CCTD in FYP. The potential application of the intervention could be shared with them to make them more receptive to their own development.
4. **Receptivity of Lecturers and Students** towards the interventions to develop creative and critical thinking in students. For example, online self-paced learning courses could be designed to take lecturers and students through the RAINBOW framework of guiding questions to develop CCTD. These could be supplemented with CoPs with lecturers sharing best practices or senior sharing tips with students.

**Implication for practice**

Table 1 illustrates how RAINBOW framework could be applied to a STEM project in Engineering.

**Table 1. Application of RAINBOW to a STEM project in Engineering.**

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| **Applying RAINBOW Framework to a STEM Project *enabling CCTD through guiding questions*** |
| **Recognise the real issue:**   * What are the clients’ **needs**? *(E.g., People with intellectual disabilities need a wearable device which tracks location to inform guardian via a mobile application)* |
| **Ask the right questions**   * What are the**Strengths/ Gaps of** **existing solutions**? *(E.g., Technology, Cost, Compatibility)* * What do we require **to fill gaps** and **fulfill client needs**? *(E.g., Parts - IoT module / Skills - Coding)* * What are the **constraints**? *(E.g., Budget/ Time?)* * How can I ascertain the **demand**? *(E.g., Survey/ Interview target Consumers)* |
| **Interlink the information**   * How to create a **better device** by selecting the **right model/parts** and using **the skills**, within given **constraints,** to meet the **demand?** *(E.g., Firebase vs Amazon Web Services Database)* |
| **N(e)nvision a solution**   * What are the most **critical features** to include? *(E.g., Location)* * Does the **solution address the gap**?  *(E.g., Test location functionality)* |
| **Balance the implications**   * How to **justify solution based on findings**?  *(E.g., more expensive & reliable technology recommended as consumers are willing to pay higher price for accuracy)* * How **does new device fare on objectives** against existing devices? *(E.g., existing devices are cheaper but less accurate)* * How to **modify design** to improve outcome? *(E.g., implement Geocoding instead of Geofencing so that location boundaries can be defined by the device user instead of fixed in the code)* |
| **Observe the changes**   * How did my **strengths/ limitations** affect the project? *(E.g., Strength- Coding helped in design)* * What have I learnt from the experience? *(E.g., understanding & meeting client needs)* |
| **Widen the possibilities**   * What could we do **better next time**? *(E.g., better time management)* * How to **use learning in future** (other module/ project/ future job)?  *(E.g., project management)* |

RAINBOW framework is a systematic approach to prepare the lecturers and students to recognise the real issue, ask the right questions, interlink the information, envision a solution, balance the implications, observe the changes, and widen the possibilities through project work. It focuses on building specific abilities and lasting dispositions which would be valued in the industry. Similar to the project shown in Table 1, this framework of guiding questions could be applied to various projects across STEM or Non-STEM disciplines to develop CCTD in students.

**Conclusion**

This study has contributed to our knowledge on the challenges faced by lecturers in supervising final year projects in an IHL and how they can be supported in developing critical and creative thinking in students, specifically during the process of supervising students’ FYPs. The anticipated outcome of this is the more deliberate integration of the RAINBOW framework into a professional development programme for lecturers and resources for students.

For STEM students, many of whom would likely join the workforce after completing their FYPs in their Final Year of study, this process could help build confidence in their ability to solve real-world problems innovatively and justify them with concrete rationale, thereby contributing to the scientific community.

The limitations of small sample size in qualitative research apply. The next step would be to translate the RAINBOW framework into e-courses and CoPs, as recommended by the findings. Future studies could be done to assess the effectiveness of the intervention in building CCTD with the IHL students or do comparisons across domains, where relevant.

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