Developing Future Computational-thinking in Foundational CS Education: A Case Study from a Liberal Education University in India

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Abstract

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Abstract—Contribution: This paper proposes a new theoretical model with a goal to develop future human computational-thinking in the foundational Computer Science (CS) education. The model blends six critical types of thinking i.e. logical thinking, systems thinking, sustainable thinking, strategic thinking, creative thinking and responsible thinking into the design of a first year undergraduate programming course. The study describes a creative blended pedagogy that embeds the proposed model into the course plan.

Background: The emergence of artificial intelligent systems such as large language models from a knowledge provider perspective, coupled with a gradual change in post-pandemic outlook of education challenge the relevance and raises concerns about the future of education. The 21st-century human computational-thinking requirements viz. learning to code (skill), and thinking computationally (competency) will be inadequate in the future. Moreover, there is substantial evidence which shows that most introductory programming courses fail to integrate critical elements like ethics and responsibility as part of the course.

Intended outcomes: The authors anticipate experiential learning models such as this has immense potential to future-proof CS education, as well as make future software engineers responsible citizens.

Application design: The proposed model blends the six types of thinking into the design and activities in the course. The underlying theoretical basis of these activities revolve around three key principles - Experiential learning, Self-Reflection, and Peer learning.

Findings: This case study from a liberal educational institution in India has qualitatively shown several evidences favouring student’s developing six critical elements of thinking that shapes their future computational-thinking ability.

Index Terms—future-thinking, 21st-century skills, foundational education, Computer Science, creative pedagogy.

Paper Outline

I. INTRODUCTION

Motivation: According to the United Nations, India ranks as the world’s top exporter of Information and Communication technology, in terms of people, products, and services. India ranks eighth in the world for producing graduates in science and engineering every year [1]. National Association of Software and Services Companies (NASSCOM) projects that by 2026, manpower requirements in the Indian IT industry will exceed 95 lakhs, of which 55 lakhs will be skilled to work across emerging technologies such as cloud computing, AI, big data analytics and IoT etc. In fact, to future-proof India’s IT industry, the Ministry of Electronics and IT Government of India, and NASSCOM have developed a joint program - FutureSkills PRIME with a goal to re-skill and up-skill graduates [3]. In the next couple of decades, as India poses to become one of the world’s leading technology and innovation hubs, there will be a manifold increase in the Indian IT talent share. More complex, expertise-based services will enable rapid growth of the Indian IT services sector. It has been projected that about 24.3% of the incremental global workforce over the next decade will come from India [2].

Advancements in digital tools and emerging technologies such as Artificial Intelligence (AI), Large Language Models, Robotics, Internet-of-Things, Big-data, Cyber-Physical Systems, etc. has the potential to make larger socio-technical systems smarter by automating processes and optimizing resource usage. In turn, enabling humankind to solve some of the grand challenges of 21st century such as climate change, sustainability, urbanization among others. However, this is only possible if we make a concerted effort to analyze how systems design thinking is changing, and what factors are driving this change. This includes, for instance, are decisions made by AI good for everyone or for some individuals or interest groups. Other questions include:

Does the availability of advanced engineering solutions and technology impact design decisions (e.g. SpiKey [4] and SmartHus [5])?

Does the urgency to mitigate climate change and drive net-zero blindfold potential risks (e.g. Lamphone [6])?

Formalizing and embedding this notion into computational design thinking is still a distant future. Unless this is done, the pervasive use of such emerging technologies in society shall possibly lead to irreversible harm. Taylor, R. et. al. highlights that one of the major problems in analyzing autonomous vehicle controllers is that of neural network components and they are difficult to analyze [9]. Another study identifies how the integrated design of smart technologies with various systems and services within the built environment transforms them into complex cyber-physical systems and thus makes them vulnerable to new risks and hazards [10].

In this context, design thinking for responsible innovation paraphrased from [7] is defined as

1 acronym for Programme for Re-skilling/Up-skilling of IT Manpower for Employability
"...a blend of art and science of solving the trilemma between understanding the benefits (e.g. reduced carbon emissions, improved sustainability) offered by a certain design approach (e.g. integrated, data-driven, participatory), together with the understanding of the landscape of risks and hazards (e.g. functional failure, social engineering, cyber threats) and their consequences (e.g. loss of lives, trust, autonomy, property damage), and thus provide the scientific knowledge and tools (e.g. taxonomy, guidelines, certification) necessary to be able to judiciously balance them during the design process.”

Hypothesis, Objective, and Research Questions: The authors argue that design-thinking of education to guide responsible innovation in society, fundamentally relies on four key ingredients, namely sustainable development, future thinking, strategic action plans, and balancing risks and benefits. Hence, the objective of this paper is to present a bespoke 21st-century education model for foundational computer science education at the level of tertiary education.

This paper proposes a new theoretical model with a goal to develop future human computational-thinking in the foundational Computer Science (CS) education. The model blends six critical types of thinking i.e. logical thinking, systems thinking, sustainable thinking, strategic thinking, creative thinking and responsible thinking into the design of a first year undergraduate programming course. We term these six types of thinking as the 6Ts model. The study describes a creative blended pedagogy that embeds the proposed model into the course plan.

The broad questions which this study aims to answer are the following:

1) Does the proposed blended learning pedagogy improve students’ critical understanding of 6Ts?
2) To what extent does the proposed 6Ts model allow the development of students’ 21st-century skills in foundational CS education?

Key contributions: This article makes two notable contributions to science education and society.

1) Introduces a new 6T model that forms the critical thinking required in the 21st century. The six Ts central to the model are compliant with key competencies and skills identified in the existing body of knowledge.
2) The study proposes a new creative experiential learning pedagogy to implement 6Ts in the design of foundational CS educational courses.
3) A qualitative discussion through a case study from an Indian university elucidates various strengths and competencies of the proposed bespoke approach.

Organization of paper: The paper is organized as follows - Section II presents the background to future of CS education from related literature; Section III introduces the proposed bespoke model - the crux of this study; Section IV introduces a detailed overview on the blended pedagogy to implement the bespoke model in a foundational CS course; Section VI presents a real case from liberal education in India explicating 21st-century skills and competencies through various learning mechanisms is discussed; Section VI a qualitative analysis of the case study to draw key insights drawn is presented; Section VII presents a comprehensive discussion answering generic questions of relevance to this special issue; and lastly, Section VIII presents conclusions drawn from this study and hints of scaling this study forward.

II. BACKGROUND AND RELATED WORK

A. Education in 21st-Century

There have been considerable proposals to bring vital change to education systems to develop useful skills that meet industry demand. These are deemed to be 21st-century skills, which when used to their full potential, can help an individual climb new heights in modern careers. There have been multiple classifications made within these skills from time to time. Although there is no proper consensus on what the 21st Century Skills are, people have attempted to classify them in accordance with their understanding of the sphere. A report from the Partnership for 21st Century Learning [35] defines three broad areas of 21st century competencies, namely - (a) learning skills (creativity, innovation, critical-thinking, problem-solving, communication, collaboration); (b) literacy skills (information literacy, media literacy, ICT literacy); and (c) life skills (flexibility, adaptability, initiative, self-direction, social and intercultural skills, productivity, accountability, leadership, responsibility).

Developing 21st century competencies is of utmost importance to face the sustainable, digital, and social challenges of the real world ethically, humanistically, and critically. With an aim to build interactive, engaging, and collaborative spaces, various stakeholders such as FabLab² and Makerspaces³ have emerged. On evaluation of their effectiveness through various focus groups, the findings clearly show that students skillfully gained skills such as planning, teamwork, public-speaking, additive manufacturing, multidisciplinary thinking, and independent work skills [34].

²https://www.fablabs.io/
³https://www.makerspaces.com/what-is-a-makerspace/
Hannele Niemi et al. [19] showed through their findings that there are some commonalities found in assessment of 21st Century Skills across academia, but the only important factor students should possess is the capacity to be consistent learners. Students, as far as possible, should never stop learning, and education globally should supplement this learning. Encouraging curiosity, inquiry, and acquisition of knowledge are crucial.

A similar view is supported by Stephanie Bell in her paper about Project-Based Learning [20] who emphasizes the effect of inquiry and ‘learning by doing’. Project-Based learning (PBL) is student-led and teacher-facilitated, wherein students formulate a question, are guided by teachers through research to dissect that question, and make discoveries through projects. Students must learn to live and work independently, but also understand the importance of collaboration.

There are also much more simplified classifications of 21st Century skills. Avid examples of the same would be Sue Beers’ extensive report on 21st Century Skills [21] combined with Daniela Cretu’s work on fostering 21st century skills amongst our future educators [21]. Both follow a similar classification which mentions the ‘Four Cs’, which are Creativity, Collaboration, Communication, and Critical Thinking.

B. Multi-disciplinary outlook in CS education

Software systems have become increasingly pervasive each day in our society. Many have argued that creators of such software systems and technologies are directly responsible for the long-term consequences of their designs [23]. However, the study of software systems i.e. computer science education has been regarded to be an extremely straightforward endeavor. A computer science engineer will use their technological prowess to solve problems they’re asked to solve. This simplification and wrongful characterization alienates complex problems that require more than a mere technical solution [24]. A dominant thought process in CS views computing as separate from other ‘social and political’ elements. Through this perspective, CS is seen purely as a ‘technical’ idea that conveniently assigns environmental, social, and political issues/consequences of the field as ‘not technical’. If the current norms of CS education are left unchecked, CS students are doomed to look for purely technical solutions to nuanced and complex social and political problems such as climate change.

It is also essential that CS curriculum help students reflect critically upon sustainability and sustainable methods pertaining to CS. Sustainability is defined as an intended approach to consuming resources that ensures today’s needs being met while also accommodating for the needs of future generations. The field is in dire need of CS professionals who not only analyze and check their work consistently, but also understand the consequences of their designs and suggest designs that level the playing field for sustainable practices. In these times, CS professionals and IT engineers can contribute considerably to achieving goals of sustainability.

However, the trend observed in the past suggests computer science education may actually lead to unsustainability rather than promoting sustainability [25]. A special session conducted to connect researchers focusing on Computing and Engineering with Sustainability reveals students often perceive sustainability and social good in CS education as ‘boring, tedious, and irrelevant’ [25]. They also explain that learning that promotes individualism and rationalism is problematic, in the sense that it does not account for social dimensions of learning, and focuses solely on reason and cognition.

There have also been attempts to incorporate modules of sustainability into existing courses. Krogtie et al. introduced a unique sustainability module into an already existing and successful course part of two separate Bachelor Degree programs in Information Technology [26]. This course develops 21st century skills in the form of enforcing a practical approach to problems and assignment of project-related works that contribute substantially to learning outcomes. According to them, giving students control and freedom over significant parts of constructing their project helps develop a sense of ‘ownership’, something previously missing from CS sustainability education.

Other researchers such as Ola Leifler et al. have attempted to integrate socially important and skills building subjects such as sustainability, ethics, and scientific writing into a module called Professionalism in Computer Science [24]. Their approach to teaching these subjects relied on flipped classrooms, educational games, discussion seminars, and having students conduct critical analyses of their peers’ IT system choices. The MSc students essays regarding the course module revealed that due to interactive learning methods, their interest in the three subjects did not wither, and they did not deem the subjects irrelevant and uninteresting to their future roles as software engineers.

Another important aspect of CS education is providing learners opportunities to be creative and express themselves. Creativity in the CS curriculum has also been observed through gamification. Gamification refers to the use of game elements in non-game environments to drive engagement in participants and inculcate desired behaviors. Any success in endeavors of gamification can be traced back to its potential to engage students in varied learning activities. This is due to the apparent positive correlation between outcomes of students’ achievements, satisfaction, persistence, and their success [27].

There are several studies which have looked at the benefits of using a gamified approach in teaching concepts. Dileeman et al. explain how effective different games can be in terms of delivering knowledge about sustainable development [28]. Pargman et al. explain how students hold a certain aversion to topics such as sustainability, and how a discussion game called Gasko led to improvement in peer learning, perspective formation, learning terminology, and teamwork [29]. Jawad et al. taught Data Structure Algorithms, Mobile App Development, and Cybersecurity through gamification [30]. Various practical games, role-plays, and class activities made the classroom engaging. Their games and gamified applications increased motivation to learn. Zainuddin [31], Margarida Romero et al. [32], and Stephen Crown [33] report similar findings, as they found that gamified settings work better than non-gamified environments in educational backgrounds.

While developing computational design-thinking in CS edu-
Fig. 2. Top 10 skills of 2025 (Source: Future of Jobs Report 2020, World Economic Forum)

Fig. 3. Proposed 6T Model for Foundational Education

cation fundamentally relies on logical thinking, several recent studies point to the fact that 21st-century skills and competencies are much broader in scope beyond logical thinking. For instance, the World Economic Forum broadly classifies 21st-century skills as having foundational literacy, competencies, and character qualities as shown in Fig.1. Note that under each of them, several abilities are identified. Another World Economic Forum study points to the fact that analytical thinking and innovation, active learning and learning strategies, and complex problem-solving have emerged as the top-3 skills in 2025 surpassing critical thinking and creativity, and people management skills from previous years. Another interesting observation pertinent to this study is the fact that creative thinking as a skill has risen from the bottom to the top four in 10 years. This indicates how various 21st-century skills changed rapidly between 2015, 2020, and 2025. It might be worth exploring how the pandemic and large-language models have altered the expectations by employers from the workforce in terms of skills and competencies. However, this is outside the scope of our study.

III. PROPOSED BESPOKE MODEL

In this study, the authors propose a new 6T model that reinforces 21st-century competencies at the foundations of CS education. Central to the model are six dimensions that develop the critical thinking required in young CS professionals at their foundational level. This includes creative thinking, systems thinking, sustainable thinking, responsible thinking, strategic thinking, and logical thinking (refer Fig.3).

• **Logical thinking** is the foundation of computational thinking and learning. It is the ability to combine heuristics, facts, and rationale to arrive at an optimum solution. Typically, CS education aims to develop logical thinking by breaking down a large puzzle into several smaller pieces, transcribing them into a pseudo-code, and weaving the pieces of the puzzle together in the form of a flowchart before actually implementing them using programmable machine-readable code.

• **Systems-thinking** Systems thinking is an approach that focuses on understanding the interconnections and relationships within complex systems. It recognizes that individual components of a system are interconnected and that changes in one part can have ripple effects throughout the entire system. This is fundamental to solving grand challenges of the 21st century including climate change, low-carbon future, urbanization, and so forth. The ability to observe the interconnections in everything - from natural to man-made systems such as the water cycle that bring rain, to urbanization paving the way for deforestation and global warming, to the use of air-conditioners - through a systems lens is an indispensable competency.

• **Sustainable-thinking** involves considering the long-term environmental, social, and economic impacts of our actions and decisions. It promotes a mindset of conservation, efficiency, and responsible resource management. Tilbury defines sustainability as ‘a way of thinking about how we organize our lives and work – including our education system - so that we don’t destroy our most precious resource, the planet....it must be much more than recycling bottles or giving money to charity. It is about thinking and working in a profoundly different way’ [14].

• **Strategic-thinking** is the ability to analyze all possibilities in order to accomplish a goal. CMOE defines strategic thinking as ‘an intentional and rational thought process that focuses on the analysis of critical factors and variables that will influence the long-term success of a business, a team, or an individual’. There are

4https://cmoe.com/
several factors favoring strategic thinking in life too. This is because decision-making is constrained by time, technology, and resources, with implications for the economy. This includes, for instance, the ability to navigate through VUCA (volatile, uncertain, complex, ambiguous) environment that cannot be controlled or predicted in advance by individuals or organizations.

- **Creative-thinking** is defined as ‘the way of thinking that leads to the generation of valuable and original ideas’ (taken from PISA). Creative thinking also develops outside-the-box thinking in individuals.
- **Responsible-thinking** is the ability to think about a problem and solution keeping in mind the global collective goodness including - personal, social, as well as environmental aspects.

In the next section, we describe the design and delivery of the course which blends the mentioned 6T model into a foundational programming course. Section VI describes key insights and findings from the application of the proposed 6T model. Furthermore, the relevance of blending six critical thinking elements through creative experiential learning modules is exemplified through several illustrious cases and discussions as presented in Section VII.

### IV. Course Design and Delivery

The proposed model is blended into a CS course viz. CSIT101-Introduction to Programming, Python. This is a foundational term course in CS education in a Liberal Educational university in India. The proposed model was implemented in Term 4 (March and April 2023) of the academic year 2022-23. An infographic illustration capturing all key details about the course along with key information pertinent to blended learning pedagogies that were employed during the term is presented in this Section IV. As seen in the Fig. 4, the implementation of the proposed 6T model requires a thoughtful design of the course. This include lesson/course plan, delivery, and learning mechanism employed. The details of which are described in detail in this section.

#### A. Course plan overview

The study was carried out as a part of the year 1 undergraduate term course on foundations of programming in FLAME University in Pune, India. The primary objective of the course is to introduce students to computational-thinking and equip them with basics of computer programming using Python language. The lesson plan details of the course is presented in Fig.5. As described the lesson plan comprises seven broad topics. This also included hands-on tutorial sessions on programming with an emphasis on learning-by-doing in class.

#### B. Lesson Plan Delivery

Central to the bespoke design of the CSIT101 course is the lesson plan delivery mechanism that blends creativity, fun, activity, and games with serious learning mechanisms incorporated in them. Fig.6 and 7 present a graphical storyboard capturing the journey implementing the aforementioned elements in the CSIT101 course through nine mechanisms each of which is described in detail as follows.

1) **'LEGO Game' as Introductory Teaching Aid:** A fun-filled LEGO-based maze role-play that blends gaming and activity to kick start the foundational lecture on computing is presented. This introductory activity is inspired by an existing online resource titled ‘Coding a LEGO maze’. In this activity, a pair of students volunteer to play the game whose goal is to help navigate a cat through the LEGO maze to catch its prey - a mouse. Between the players, they use a pack of instruction cards to facilitate the navigation in sequence. At the end of the game, a debrief is carried out to reflect on the similarities in the roleplay between the two players with that of computer/machine and programmer. Besides, the relevance of any computer programming language consisting of (high-level) machine interpretive instruction sets, sequential execution of instructions, and the compiler were all introduced through games as a teaching aid.

2) **Micro-Lectures:** typically are designed to last for 15-20min blended within my regular lecture hours (2hrs), delivered by subject-matter experts either physically in-person or digitally remotely with the intention to sensitize key topics that entail 6Ts. As an example, a practicing lawyer and a practicing architect gave micro-lectures sharing unique global perspectives about the law surrounding ethics of data, computing, and AI; and energy-efficiency, resource conservation, and climate-sensitive sustainable design respectively.

The purpose of the micro-lecture series is to seed multidisciplinary thinking at the grassroots level of CS education. Thus, co-facilitate critical thinking and develop next-generation responsible STEM/STEP professionals.

3) **Guided Walk:** The objective of the guided walk is to teach students to develop the ability to observe systems in the wild, and thus develop an innate cognizance of systems around them. For instance, hostel rooms, nature, campus, classrooms, dining halls, cafe, gymnasium etc. During Week 3 of the course, a ‘guided walk’ activity was facilitated by the instructor. The purpose of this activity was to educate learners about observing systems in the wild as one of the key 21st-century skills. The guided walk is conceptualized as an active mode of education that encourages students to learn from anything and everything around them, develop their cognizance to a larger real outside world around them, build their sociocultural awareness, and so forth. The guided walk in CSIT101 provided an opportunity for students to engage in conversation with the faculty mentor through observations about work of a security watch-guard, building construction, drip irrigation, life on campus and many more.

4) **Creative Project:** One of the bespoke aspects of this foundational course on programming and computational-thinking is the creative computational project by students in groups of size three. The central purpose of the project is to apply creative-thinking in the design, development and

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3OECD Programme for International Student Assessment
https://www.oecd.org/pisa/

6https://researchparent.com/coding-a-lego-maze/

7wooden toys cat and mouse were used for the visual appeal of the game
Fig. 4. An Implementation of the proposed model in the Foundational CS Education

Fig. 5. An overview of the course plan: CSIT 101 Introduction to Programming, Python

<table>
<thead>
<tr>
<th>Topic 1</th>
<th>Introduction to Programming</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topic 2</td>
<td>Variables and Expressions</td>
</tr>
<tr>
<td>Topic 3</td>
<td>Data types</td>
</tr>
<tr>
<td>Topic 4</td>
<td>Branching and Looping</td>
</tr>
<tr>
<td>Topic 5</td>
<td>Functions, Modules, and Classes</td>
</tr>
<tr>
<td>Topic 6</td>
<td>Introduction to Numpy and Pandas</td>
</tr>
<tr>
<td>Topic 7</td>
<td>File Handling and Plotting</td>
</tr>
</tbody>
</table>

21st Century Skills and Competencies

Demonstration of the project instead of a regular computer coding. The project life-cycle phases also have varied goals to accomplish. The broader design goals include embedding foundations of computing and programming concepts and terminologies, build innovative application prototypes, create fun and interactive artefacts etc. in a creative manner. This requires a holistic understanding and applications of 6Ts.

The development goals embeds translating the comprehension of 6Ts and incorporating them in the creative process of development (for instance, employing circularity or 3R principle from sustainability in the development of the project). The demonstration goals entail embedding elements that stimulates interaction and facilitates engagements among peers. Some creative demonstration include role-play, activities and games using cards, boards and so on.

The creative student projects such as Energy Calculator (see Fig. 8) and EcoFlow (poster not included in the article) exemplify how blending applied creative pedagogies such as guided walks, micro-lectures, and creative projects triggers or serve as stimuli for students to conceptualize innovative projects at the nexus of computing, sustainability, and behavioral sciences.

In the Energy Calculator project (see Fig. 8), a bunch of students stretched their imaginations and thought out-of-the-box to develop a simple personal energy calculator by observing systems around them in their daily lives in student rooms on campus. This includes lights, mechanical ceiling fans, and air-conditioners. They collected typical energy consumption figures based on a common model of appliances that were installed across student rooms. The actual project demonstrated was made interactive and engaging by involving their peer in the class. The underlying notion of the project was to sensitize peers about their personal energy consumption patterns and gradually improve energy efficiency by stimulating behavioral change through simple changes in their day-to-day activities such as turning-off appliances when stepping out of their rooms. They designed a simple flowchart in a physical poster incorporating simple arithmetic operations in sequence and guided narration to facilitate their peers to make self-estimates of energy use (on paper). At the end of the activity, they used nominal values of individual energy use (for men and women) in their discussion to stimulate behavioral change.

Likewise, another group of students developed a creative project called Eco Flow at the nexus of computational design, sustainable water resource usage, management, and security, and behavioral sciences. The fundamental notion of the project is similar to that of the Energy Calculator, but the difference is the resource that was considered here - Water. Another difference is, unlike Energy Calculator, the Eco Flow project designed a simple Python program instead of a physical poster, and instead of making self-estimates by students, the Eco Flow used peer interaction to collect information pertinent to an individual’s typical daily habits/routines that are dependent on the water resource. When entered all the figures, the
Python program produced an estimate of annual water usage in liters. At the end of the activity, they used nominal values of individual water usage (for men and women) in their discussion to stimulate behavioral change.

Each group was given approx. 10 minutes, where demo/presentation lasted for 8 min followed by 2 min for questions, answers and comments from peers. In addition, every project team prepared a digital poster describing and reflecting their creative project as well. Significance of digital archival, referencing/citation, redistribution, publication etc. of their creative works was encouraged. Certain guidelines to design and development of the infographic posters were given. For an example reflection poster refer Fig.8.

All creative student projects were evaluated based on 6 metrics. This includes originality, relevance to computing, embedding 6Ts, creativity, class engagement, and overall project management skills.

5) Tutorial sessions:: These are typically reserved for learning and trying your hands-on coding in the presence of an instructor. During these sessions, students were given questions, and the objective was to help them learn how to develop the pseudo-code/algorithm (first), and then use programming construction (learned in the class) to build a computational solution in Python on Jupyter Notebook. The instructor was present to clarify their questions. It is not an exam but a practice session.

6) Baseline and end-term questionnaire:: Two simple survey instruments were provided to students individually both at the beginning and end of the course allowing them to reflect on one scenarios pertinent to each of the 6Ts to gauge their level of understanding on each of them qualitatively.

C. Focused Learning Mechanisms:

Typical CS foundational courses would otherwise focus on passive learning through regular lectures and learning-by-doing through tutorial sessions on computer programming/coding. However, in contrast, our CSIT101 blended learning class was designed consciously to integrate four key learning mechanisms (see Figure 4). This includes conventional learning (i.e. learning through lectures, tutorials), experiential learning, self-reflection and peer-learning. Self-reflection is facilitated through structured reflection aid (e.g. poster, canvas) at the end of every activity/game. On the other hand, peer learning is facilitated through co-working on creative projects in teams, and interactive demonstration of the same to their peers in the classroom setting. In the next section, we describe these learning mechanisms in detail.
V. APPLICATION DESIGN

In the previous sections, we proposed a model which aims to integrate the essential 21st century competencies into an introductory programming course, and described how these skills were blended into the course design. In this section, we outline the theoretical considerations underlying the design of these activities. The design and activities in the course revolve around three key principles - Experiential learning, Self-Reflection, and Peer learning.

A. Experiential Learning

Experiential learning refers to the learning that has been acquired by doing certain activities. The aim of an experiential learning approach is to immerse learners in an experience and then encourage them to reflect on their experiences in order to develop new skills, new attitudes, or new ways of thinking [15]. Specifically, we adapted the Lewinian experiential learning model as the primary design driver of our activities [16]. This model has four key stages. In the first stage, learners are introduced to concrete experiences. They then observe and reflect on these experiences, and abstract out relevant concepts. Finally, they test out their understanding of these concepts in different situations.

The Lewinian experiential learning model served as the underlying model for the key activities of the course, such as the micro-lectures, guided walk, and the creative project. Through the micro-lectures, learners were introduced to several concrete experiences and perspectives of experts who applied critical thinking skills in their day to day work. Through these lectures, abstract critical thinking concepts were grounded on real-life experiences for learners.

A key tenet of experiential learning is facilitating transactions between a learner and his/her environment [16]. The guided walk served the purpose of sensitizing learners to experience the environment around them and glean out critical thinking as well as socio-cultural aspects from their surroundings. We draw inspiration of the guided walk from Palm et al. who proposed a similar strategy - ‘walking with energy’ to drive energy citizenship that enables citizens to (re)connect with where their energy is coming from [11]. They employed four creative methods, namely, (a) a physical walk to an energy recovery facility, (b) a walk to view a building’s heat exchanger, (c) a round-table discussion using pictures to communicate in a language café, and (d) a virtual tour around an energy recovery facility. The objective of this new approach is to investigate how creative approaches such as viewing (through a guided walk) and talking (discussions)
about heating provision can encourage participants to reflect upon their mundane energy-use behavior, foster a greater sense of energy citizenship, and further motivate them to engage with debates around heating transition (in UK and Sweden).

Through project-based learning (referred to here as creative student projects), we provided opportunities for learners to test their understanding of the concepts they acquired through different activities like micro-lectures and guided walk. We believe these activities triggered learners’ thinking toward looking at building creative projects from a critical, socio-technical lens.

To summarize, we believe that grounding students’ learning in relevant experiences is the primary way in which students will acquire necessary critical thinking skills. The Lewinian experiential learning model served as the basis for key activities of the course, which enabled learners to experience and abstract out critical thinking skills, and also test their understanding by creating creative projects.

B. Self-Reflection

Self-reflection is the ability of an individual to assess and adapt their thinking as they go about performing a task [17]. It also involves introspection and examination of one’s thoughts, feelings, and behaviors. Through self-reflection, individuals can identify areas for improvement, learn from past experiences, and make intentional choices that align with their values and goals. Reflection is particularly important as learners grapple with critical issues, as it is in the process of reflection that learners seek to understand their underlying thought processes and convictions towards a variety of critical and ethical issues. We draw on Schon’s framework on reflective thinking to characterize reflective activities in our course. The framework describes two key types of reflection - reflection-in-action (i.e. reflection during an activity) and reflection-on-action (i.e. reflection after performing an activity) [18]. An example of reflection-in-action is based on the design of posters that students created as part of their creative project. They were asked to explicitly reflect on how they incorporated different types of thinking from the 6T model in their projects. An example of the reflection-on-action is the baseline and end-term questionnaire which students had to answer. Answering these questions related to the six thinking skills enabled students to reflect on how their understanding changed from the start of the course towards the end of the course.

C. Peer learning

A key design decision of the course is that opportunities were provided to students to learn from their peers. This was primarily facilitated by the creative group projects which students had to do. Coming up with a creative idea, planning and executing the idea involved all members of the group to collaborate with each other.

VI. ANALYSIS AND FINDINGS

In this section, we examine student projects and posters to understand how students have reflected on and imbibed various critical thinking elements. The main artifact which was used in the analysis were student posters, that served as the reflection canvas of the outcome of project-based learning. One of the authors analyzed the poster corresponding to each project. The author analyzed each poster sentence by sentence and categorized the sentence into one of the dimensions of the 6T model if there was a close match. The findings were represented as a table. After the initial analysis, the author discussed the analysis with two other authors. The three authors then discussed, and came to an agreement on the categorisation.

A summary of the findings is shown in Table I. From the table, we see that each project contains most elements of the 6Ts. We describe instances of student reflections of each of the 6 thinking skills below.

Creative Thinking: We saw several instances of creative thinking in student reflections. First, students mentioned that they creatively used various stationary such as chalk, scissors, paint, miniature models, etc to create elements of their projects (e.g. Brain Gain, Energy Consumption). Second, in projects which involved creating games, students found that coming up with the game elements and strategy was a creative endeavor. Games like “Guess Who?” and “Dream Home” involved persons playing the game to come up with creative strategies (Example quote from poster - “We tried to keep an open approach to the game, giving the player a simple layout on a page, and leaving the rest up to their creativity”)

Sustainable thinking: The projects helped students model sustainable thinking in several ways. First, in most projects, students created the projects using materials such as re-used cardboard and paper, thus promoting sustainability in terms of materials. The core theme of other projects were issues related to sustainability, such as energy conservation and water conservation (Example quote from the EcoFlow poster - “The game raises awareness about water conservation, thus promoting sustainable habits.”)

Responsible thinking: Students reflected on how their projects promoted accountability and responsibility of user actions. For example, in the project Ecoflow, students mentioned that the game “instills a sense of responsibility by tracking and displaying individual water consumption thus, encouraging players to be accountable and promoting responsible behaviour towards water usage.” In the project “Dream Home”, students reflected on how the game makes participants understand the implications of their actions, thereby promoting responsible thinking (Example quote - “When the player draws on their sheet, their mark is made. These cannot be erased, and the player will have to bear the loss of the resources, and also work around it for their future decisions”)

Systems thinking: We observed several student projects inculcating systems thinking in their work. In the project “Energy Calculator”, students reflected on how the aggregation of multiple applications resulted in the energy consumption of a room (Example quote - “The flowchart merges different aspects (energy generated and used by different appliances like AC, light bulb, fan) of energy conservations into a single flowchart”). A similar systems thinking outlook was observed in the the projects Ecoflow (example quote: “Players are
<table>
<thead>
<tr>
<th>21st-century competencies</th>
<th>Brain Gain</th>
<th>Energy Calculator</th>
<th>EcoFlow</th>
<th>Guess Who?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creative thinking</td>
<td>Adopted open-source DIY framework for card and board design. Handmade using chalk, paint, paper, and cardboard</td>
<td>Handmade miniature models mimicking appliances in student hostels</td>
<td>An interactive mini computer-based game</td>
<td>A competitive guess game with 2 identical sets of baseboards and 32 flip cards</td>
</tr>
<tr>
<td>Sustainable thinking</td>
<td>Entire game was made by deconstructing an used cardboard box</td>
<td>The project is about energy conservation. Models appliances such as lights, fans, and air-cons were made from reused newspapers</td>
<td>The game is about sustainable water use and conservation</td>
<td>Entire board game and cards was designed using reused cardboard and paper</td>
</tr>
<tr>
<td>Responsible thinking</td>
<td>NA</td>
<td>The activity encourages responsible usage of electricity in hostel rooms</td>
<td>The game instills a sense of responsibility by tracking and displaying individual water consumption; encouraging players to be accountable; thus promoting responsible water usage</td>
<td>The game is entirely reusable. Game serves as a fun-filled activity-based self-learning aid to learn programming</td>
</tr>
<tr>
<td>Systems thinking</td>
<td>NA</td>
<td>activity develops a broader systemic view of individual human activities and water usage, and impact on the campus water demand and management</td>
<td>NA</td>
<td>game encourages players to merge smaller shapes through sketching to create larger functional components (e.g. triangles+rectangles to make doorways) in a building design</td>
</tr>
<tr>
<td>Strategic thinking</td>
<td>NA</td>
<td>Used energy consumption of households in a village as anecdotes to stimulate behavioural change</td>
<td>Players must plan their activity schedule beforehand, and optimize individual water usage effectively before it runs out</td>
<td>Determine the programming terminology behind the 'Guess who?' card through tactical question that eliminates maximum no of incorrect possibilities</td>
</tr>
<tr>
<td>Logical thinking</td>
<td>NA</td>
<td>The calculations for energy estimates are based on logical questions and answers, including simple Boolean algebra</td>
<td>Players need to make logical decisions and strategize their water usage to stay within their daily limits, avoiding penalties and water shortages.</td>
<td>The players must carefully think about how they utilize the individual parts/functions to create their desired house</td>
</tr>
<tr>
<td>Computational Thinking</td>
<td>NA</td>
<td>Prompts users for their inputs, and use the algorithm to guide peers to make computations (process), and self-estimate (output) one’s energy usage.</td>
<td>Incorporates programming concepts and variables, lists, and operators to estimate water usage and conditional statements to simulate rational water usage and promote conservation.</td>
<td>With limited resources, players are forced to logically design their dream home with end goal in mind</td>
</tr>
</tbody>
</table>

**TABLE I**

**SUMMARY OF FINDINGS - INSIGHTS FROM STUDENT PROJECT REFLECTION POSTERS**
required and encouraged to consider the interconnectedness of water usage within the hostel system, in an effort to understand that everyone’s choices impact the overall water supply and fostering a systemic perspective on resource management.”

and “Dream Home” (Example quote - “System thinking is a way of looking at complex systems, as a whole and understanding how different parts interact. It is represented in the need for players to understand rules of merging smaller parts to create something larger and the various trade offs that they receive in decision making of the parts they choose.”)

Strategic thinking: In most projects, we observed students reflecting on how the strategy of playing the game promoted strategic thinking among players. In the project “Guess Who”, students reflected on how “…the team guessing the answer has a limited set of questions. So they must find the best possible way to eliminate maximum possibilities.”. In the project “EcoFlow”, students mentioned that “players must plan their water usage beforehand, and optimize their resources effectively to ensure they do not run out of water.”

Logical thinking: Students used logical thinking in their projects in several ways. In the project “Energy Calculator”, the calculations for each question was based on logic and boolean logic. Students reflected on how the project “Guess Who” “implements deductive reasoning with which players logically narrow down the possibilities to reach the correct answer.” Hence, the mechanics of understanding what sort of calculations are required, and what decisions have to be made promoted logical thinking among students.

Computational thinking: All projects involved incorporating programming and computational thinking concepts in a creative manner, and this was evident from student reflections as well. The objective of projects such as “Brain Gain” and “Guess Who” was to teach players playing the game important programming concepts such as variables, input/output, conditionals, loops and functions. In the “Dream Home” project, students felt that advanced concepts were also introduced (examples, loops and functions). In the “Dream Home” project, students mentioned that “players conserve energy conservations into a single flowchart.” The users are inspired to strategically reduce their energy usage below a certain threshold.

We realized that this is not the result of not caring, but instead the result of a lack of consciousness about their own contributions to energy consumption. Thus, we designed a project that can facilitate such consciousness.

Logical
The calculations for each question are based on logic, including Boolean Logic.

Sustainable
The premise of the project is energy conservation. It also involves models made from reused newspapers.

Creative
Visual representation of important questions, along with use of handmade miniature models.

Technical
The flowchart merges different aspects of energy conservation into a single flowchart.

Strategic
The users are inspired to strategically reduce their energy usage below a certain threshold.

Responsible
The project encourages responsible usage of resources provided to a person.

VII. DISCUSSION

The discussions presented in this section aims to present how our study provides evidences which aim in answering the research questions of relevance to this special issue; namely

1) How to enhance learners’ broad spectrum of 21st century competencies and thinking skills, and how to apply these in civic engagement and real-world contexts.

2) How to enhance the relationships and dialogue between actors of the educational community: student-teacher, teacher-teacher, teacher-researchers, outreach communities, and all stakeholders involved.

Fig. 9. Creative Demonstration of Guess Who? game
We present evidences from students’ creative projects (the outcome of project-based learning) such as posters and pictures curated from the course and related state-of-art research methods. We provide several qualitative evidences which show how students demonstrate the application of critical thinking skills throughout the course. Specifically, students’ projects such as Brain Gain, Guess Who? and Dream Home blends art, creativity, and fun to foster interaction in the class during project demonstration and facilitated peer-learning about basic computing, programming concepts/terminologies, and reinforced critical thinking.

In previous sections, we described the ‘guided walk’ activity, which finds similarity with Palm et al.’s “walking with energy” strategy. Such guided walks provide a lot of rich insights into applied creative education. Firstly, ‘the walking with energy’ method encouraged sharing personal experiences through storytelling and deepened the engagement of participants with debates about energy. Secondly, it helped promote energy democracy and boost a deliberative dialogue about present and future energy systems among citizens. Lastly, it showed that the promotion of energy citizenship requires not only active citizens but also active facilitation that provides opportunities for citizens to deeply engage and reflect. This study is a very good example of how civic engagement and real-world societal contexts can be blended to develop a new creative teaching methodology required to educate 21st-century skills and competencies such as collaboration, communication, creativity, critical thinking, and problem-solving.

The creative student projects such as Energy calculator and EcoFlow serves as exemplary evidence of how applied creativity and blended learning enable the development of innovative prototype solutions (in teams with their peers) in the classroom by embedding principles and 6T concepts learned during the course. In addition, such creative projects when guided and nurtured well during subsequent years of undergraduate education can possibly pave the way for students to scale these projects beyond their classroom to civic society (e.g., K-12 schools), and build socially impactful enterprises to shape the low-carbon future of the society.

Besides Energy Calculator and Eco Flow, the student projects in the CSIT101 course also produced several other interesting games and activities worthy of discussion. For instance, Brain Gain (see Fig.10) is a board game using dice and cards to prompt questions that test players understanding of the fundamentals of the 6Ts key to critical thinking. As can be seen in Fig.10 players start from one common point and traverse around the board (guided by rolling die), every time a player land on one of those colored boxes (labeled as systems-thinking, creative-thinking, strategic-thinking, logical-thinking, sustainable-thinking, and responsible-thinking), they will be prompted to select a random card from the pack of questions cards corresponding to that category that tests that fundamental knowledge on the same. When answered correctly, the player earns a point and moves ahead in the game. The game plan repeats with all players and whoever completes traversing the board once earning the maximum points, is deemed the winner.

All these games serve as classic evidence exemplifying how the proposed blended pedagogy nurtures all 6Ts - creative thinking, systems thinking, logical thinking, sustainable thinking, responsible thinking, and strategic thinking by encouraging play/game-based learning, allowing time to focus, fostering reflective reasoning consistent with World Economic Forum’s report on the new vision for education [8]. Thus, learning 21st-century competencies and skills is made experiential by blending fun, interaction, and engagement effectively within the foundational CS education.

**VIII. Conclusion and Future Work**

The future of education is experiential. This study presents a new model integrating 6 core thinking elements (6Ts) that are key to strengthening critical thinking required in the 21st-century. Furthermore, we present a new pedagogy in a foundational CS programming course that allows embedding the 6Ts and facilitating them in an experiential way relevant to education in the 21st-century.

Our analysis and findings provides evidence to answer the broad question of whether the proposed blended learning pedagogy improved students’ critical understanding of the 6Ts. Almost all students’ creative project posters have direct evidence from self-reflection of their critical understanding of all 6Ts. While several creative project teams had a significant scope to embed all 6Ts and articulated it well, others had a limited scope to embed them all. The proposed 6Ts model allowed students to comprehend and internalize 21st-century challenges fairly well. In fact, the project-based learning approach has untapped the creative potential to experientially learn and practice the three step responsible design-thinking approach i.e. observing systems in the wild, critical reasoning and enquiry, and a responsible action plan. The innovative
prototype solutions they developed are testimonials to tackle some of the pressing global challenges such as energy efficiency and water security. In addition, the project reflection canvas also provides strong evidence supporting this claim. The study thus concludes that the creatively blended learning pedagogy proposed in this study allowed students to critically develop their future computational-thinking ability.

Future Work: In addition to the qualitative analysis of the proposed model, we have also carried out a quantitative study. Our next step is to present the evidence from a natural experiment that compares the performance of two groups of the same cohort - one exposed to blended learning pedagogy, and the other to conventional programming pedagogy.

Experiences from teaching and co-creating creative experiential learning modules and artifacts allowed building Kalluri’s Urban Design and Open-innovation Studio (KUDOS) at FLAME University with a seed fund from the university. KUDOS is built with a mission - The Future of Urban X with the ethos of blending art, fun, creativity, education, and foresight as the guiding philosophy. Currently, KUDOS is building a series of experiential learning modules around the theme of complex urban systems which is planned to be piloted in the forthcoming summer course school at the university at the undergraduate level. All these game-based learning modules are being co-created through research and collaboration with experts drawn from diverse disciplines and professions. This includes a not-for-profit organization working in the digital transformation of governance and a national institute on urban development and management based in India, a global healthcare enterprise based in India, a Norwegian research institute, and academic researchers from Economics, Public Policy, Educational Technology, Computer Science, and Liberal Education. An example creative educational module is based on a board game which is in its beta version of development and testing. This serious game is called Building-in-a-Box with a goal to teach/learn ‘what makes buildings and facilities in an urban environment a complex socio-technical system?’. As next steps, KUDOS is aiming to scale these experiential games and lesson plans beyond FLAME University nation-wide through a hands-on creative learning workshop to be hosted in the forthcoming International Conference on Technology 4 Education (T4E 2023) which is premier forum organized by EdTech Society of India. Likewise, KUDOS also plans to scale these serious experiential games and activities to accelerate urban innovation through systemic education across K-16 education with strategic partnerships. A focused workshop on the theme of ‘21st century Education and Creative Experiential Learning’ was held in early June’23 between KUDOS and the Council for Creative Education Finland allowed identifying strong areas of synergies and strategic pathways for collaboration in scaling KUDOS beyond FLAME University and India.

As the lead researcher and educator, developing creating experiential learning modules rooted in scientific research has opened-up a new world of possibilities and opportunities to create social impact. For instance, KUDOS is currently looking for serious partners and collaborators to co-create serious social games/activities (based on computer-based or physical) that allows playing in teams with a collective mission of ”net-zero!”. Such serious games can be facilitated as a social activity involving residents in housing complexes/societies, and/or involving students in class rooms, and/or involving employees/staffs in campus estate management in universities, and/or department heads in public/municipal offices, too. These games are not only socially engaging but also serious with deeply connotations weaving socio-cultural, and/or geopolitical constructs drawn from real-world into the fabric of the game and lesson plan.

Games such as these shall open a whole new topic for public debate and policy innovation through scientific research. It will facilitate investigating:

1) how games and activities allow reflecting deeply on the urgency and collective cause/action?
2) how many agree that sharing their data and best practices creates a large (pro) socio-environmental impact?
3) what players report as concerns, challenges, and barriers at the individual level? and based on the above insights
4) investigate how powerful and/or practical and/or far digitalization and democratization drive decarbonization?

Such games can then be distributed under Creative Commons license agreement amongst our academic network (e.g. alumnus, forums8) encouraging peer group instructors and educators to use them in their classroom and professional networks by providing them with a game facilitation guide for free. All these efforts shall culminate in launching a bespoke MOOCs course on the theme ‘Experiential learning of 21st century skills and competencies’.

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