Comparing Computational Thinking in Scratch and Non-Scratch Web Design Projects: A Meta-Analysis on Framing and Refactoring

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Abstract. Development of computational thinking (CT) covers a broad range of skills, as exemplified by diverse CT definitions and assessments. There are however, less research on developing computational perspectives. We aim to investigate how to develop computational perspectives, critical to creativity and innovation, within the Interest-Driven Creator (IDC) theory, which espouses constructivist/constructionist tenets. This paper reviews the foundational works on design thinking, computational thinking and creativity. We then analyse examples in computing and information systems, and one in the creative industries, to derive pedagogical-socio-technological insights. We find that non-Scratch projects, will benefit from framing, via diverse human-computer interaction (HCI) design grand challenges and task refactoring. We also find that designing based on goal-based scenarios, and strategic knowledge, with scalability and extensibility in mind, e.g., via Alexandrian architectural patterns, and logical flow of information, will extend association to aggregation (abstraction). This is followed by refactoring and/or permutations at different levels of granularity. We also find that Scratch's diversity and underlying design thinking-CT/data science-participatory-knowledge management design are critical to non-Scratch CT projects' success.

Keywords: Computational thinking, design thinking, IDC theory, (non)-Scratch projects, flow, patterns, refactoring

1. Introduction

Wong, Chan, Chen, Looi, Chen, Liao, King and Wong's (2020) interest-driven creator (IDC) theory builds on goal-based scenarios, constructivist-constructionist foundations, socio-technical-pedagogical knowledge building tenets and design thinking motivations. The IDC framework revolves around the interest loop (develop/widen interest), creation loop (learn/develop creativity by designing, hypothesizing and prototyping) and habit of practice loop.

Our focus is on developing computational thinking skills. When we think of Computational Thinking (CT), Wing's (2006) emphasis on using computer science to address real-world problems, comes to mind. Since computer science is not easily understood by many, Brennan and Resnick's (2012) CT approach, focuses on building computational concepts, practice, and perspectives. Moreover, human-computer interaction (HCI) forms and refines mental models. Consequently, building on Brennan and Resnick's (2012) CT approach, Harvard's ScratchEd analyses diverse case studies on how interaction designers design, and specifies skills that we need to develop (Table 1).

Table 1. *Scratched's Definitions, Based On Brennan and Resnick's (2012) Concepts, Practice and Perspectives*

Computational perspectives (communicative)	Computational concepts	Computational practices
- express (and increase in confidence as a creator), - connect with others to create - hypothesize to improve the world	- seven main concepts - sequential and parallel information processing, iteration, - triggered by events, controlled algorithmically by conditions	- incremental and iterative, - experimentations, - testing and debugging, - reusing and remixing - abstracting, modularizing

1.1 Problems and Objectives

There are many well-established research on computational concepts and practice. Our focus is on developing perspectives, based on ScratchEd's computational perspectives (expressing, connecting and wondering/hypothesizing). *Framing is an established design method to develop perspectives. However, what should framing be designed or be based on?*

Lee, Wong and Lau's (2015) study finds that interaction design based on not only design patterns but also user experience, and sustainability in non-Scratch Web design projects, would enable better prediction of CT skills among engineering tertiary students. HCI connects conceptual and process models, resource management and knowledge tracing more, ontologically, experientially, cognitively and emotionally. The 2018 ACM HCI student design competition foci, and Schneiderman, Plaisant, Cohen, Jacobs, Elmqvist, and Diakopoulos's (2018) grand challenges (Table 2) provide further options.

Table 2. *Options for Students' Foci*

2018 ACM Human-computer interaction design student competition			**Some of Schneiderman, Plaisant, Cohen, Jacobs, Elmqvist and Diakopoulos's (2018) grand challenges**		
healthcare	policy, public service	*business development*	amplify empathy, compassion	shift from UX to community experience	encourage reflection, calmness
aging	sustainable living	education	stimulate rapid interface learning	promote life-long learning	

Due to the key roles of patterns and assessment in CT development, Lee and Jiang (2019) have aimed to connect CT assessment with HCI design in Scratch fractal projects by young children. Moreno-León, Robles and Román-González's (2015) CT assessment rubrics is used to assess CT characteristics. Findings indicate that overall, flow control, is the most important contributing factor, followed closely by data representation and logic (Table 2). The process flow/algorithmic logic, which connects entities, creates actions@fun/attraction. Furthermore, the highest scoring groups utilize abstraction, logic, different media/channels and awareness of audience to create diverse perspectives/remixing/ transformation. This is admirable, confirming that abstraction, logic, and multimodality, may be good predictors of CT skills, with HCI and design patterns as triggers/mediators and guides.

Table 2. *Lee and Jiang's (2019) Comparative CT-HCI Predictors*

Overall group	**Highest scoring groups (score in parenthesis)**	**Predictors (difference between overall group and highest scoring groups)**
• flow control (46) • data representation (45) • logic (42) • abstraction (41)	• data representation (3), abstraction (3), • logic (3), mastery (3) • flow control (2), interactivity (2)	•CT score for mastery increases with logic & abstraction, • music adds a sensorial channel • objectives & instructions (goals/context)

Kruschitz and Hitz's (2010) analysis of design patterns commonly used in books, scientific papers and online resources, finds that the most frequently used content elements in design patterns are mostly Alexandrian, i.e., Pattern Name; Problem-context, summary, author name; Forces; Solution; Examples; Related Patterns; Aggregation (scientific) and Association. They consequently suggest that a taxonomy should be developed to enable not only easier search, but also increase learning gains. We surmise that such taxonomy should be based on or similar to Bloom's progressive revised taxonomy. Pursuant to these findings, we aim to investigate *are there similar CT characteristics in non-Scratch HCI projects, among computing and information systems students?*

We next review related foundations, analyse examples of design variations in a HCI course, to identify important design factors for-, and post-pandemic; and pedagogical design implications.

2. Related Work and Discussion

2.1 Goal-Based Scenario, Knowledge Building and Epistemic Agency

Scardamalia and Bereiter (2002) opine that knowledge building based on socio-technological impacts may help students to better develop holistic modelling and relations among stakeholders and processes. Clarifying these is more likely to result in intrinsic goals, clearer and more accurate scenarios and subsequently, higher confidence and epistemic agency. To scaffold knowledge building, the use of Schank, Fano, Bell and Jona's (1994) goal-based scenarios (GBS), has been critical, as the rationale underlying actions and goals (knowing why), is more likely to motivate curiosity to know. GBS also simulates HCI's Goals, Operators, Methods and Selections (GOMS).

2.2 Computational Thinking, Diversity, Creativity

Spiro, Coulson, Feltovich and Anderson's (1988) Cognitive Flexibility Theory (CFT), highlight how structured reflection/analyses of (un)structured variations can sometimes, encourage incremental self-rectification, along Gero's (1990), Goel's (1997) and ScratchEd's progressive continuum.

To promote analogical thinking and creativity, Gero (1990) defines creativity as routine if there are similar design variables and range of values; innovative if there are similar design variables, but modified range of values; and creative if there are modified design variables and range of values. Goel's (1997) model-based analogical processes, highlights AI-based planning, influences retrieval, adaptation, instantiation, decomposition and evaluation of entities and processes/behaviours. Over time, with more examples, abstractions can be derived to form rules in the knowledge base.

2.3 Human-Computer Interaction

Human-computer interaction (HCI) forms and refines mental models. Good design bridges gaps in these mental models. Two human-computer interaction (HCI) standards/principles, i.e., Nielsen (1995) and Schneiderman's (1998), focus on user control and reduction of cognitive load, while Norman's (1998), focuses on affordances, mapping and feedback to overcome constraints. HCI builds on the above foundations for meaningful learning.

3. Methodology

We analyse the best performing assignments for the course Human-Computer Interaction, carried out during the August-December 2020 semester in Sunway University, Malaysia. The Sunway University students are from the Computer Science, Information Technology, Computer Networks and Security, Software Engineering, Information Systems and Mobile Computing with Entrepreneurship programs. Structured based on the Systems Development Life Cycle (Valacich, George & Heffer, 2015), students are asked to choose two foci: one from the 2018 ACM HCI student design competition foci, and one from Schneiderman, Plaisant, Cohen, Jacobs, Elmqvist, and Diakopoulos's (2018) grand challenges, or both from the ACM HCI competition or both from Schneiderman et. al.'s grand challenges. They are then asked to identify worthwhile/interesting and sustainable gaps based on the two foci and to do a SWOT analysis between prior reviewed studies and their proposed system. This is to establish the *why* for design.

The students range from those in semester 4 to semester 13. Calibration to students' abilities is via refactoring of tasks/scope.

- 3. Review papers above the year 2018 and 5 systems/apps in the market. 4. Do a SWOT analysis with a table of comparison of functions. 5. Elaborate on the opportunities that you identified in relation to societal and individual impact. 6. List the proposed functional requirements. (Review papers and apps (Functional_comparison (SWOT (Opp_impact (FR))))).
- 3. Review papers above the year 2018 and 5 systems/apps in the market and compare, using a table of comparison of functions. 4. List the proposed functional requirements. 5. Do a SWOT analysis in relation to societal and individual impact. (Review papers and apps (Functional_comparison (FR (SWOT (Opp_impact))))).
- 3. i) Review a) papers published in the year 2018 and above and b) 5 systems/apps in the market. ii) Compare the 5 apps with your proposed system, using a table of comparison of functions. 4. List the proposed functional requirements. 5. Do a SWOT analysis in relation to societal and individual impact. (Review papers (Functional_comparison (apps (FR (SWOT (Opp_impact)))))).

Next, Schneiderman et. al.'s (2018), Preece, Sharp and Roger's (2015) guidelines, Nielsen (1995) and Norman's (1998) theories and guidelines, are used as design guidelines. Carnegie Mellon University's Information Systems Analysis and Design project rubric is used to score the assignment outcomes. UI/HCI design patterns are introduced but is optional, i.e., based on students' discretion.

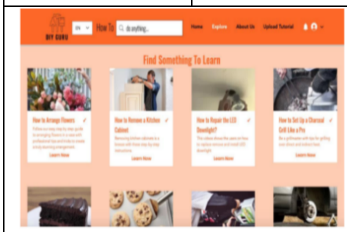
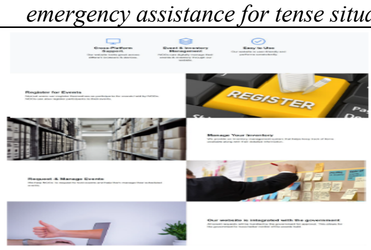
Subsequently, they are tasked to evaluate their proposed prototypes via questionnaires developed based on the common HCI metrics of their choice, e.g., heuristic evaluation. We next compare findings with an example of a Design Research assignment in the creative industries, in Universiti Tunku Abdul Rahman. To analyse, Goel's (1997) *what/how* (content analysis) are applied.

4. Findings

4.1 In Computing and Information Systems

The examples analysed, are arranged in a spectrum, in Table 3 below. They are extracted from the best-performing assignments, on the theme COVID-19 pandemic applications. The ACM HCI challenge foci (in normal font) and Schneiderman et. al.'s grand challenges (italics) are students' choices.

Table 3. *HCI Student Projects*

Project	Foci	Problems and opportunities, societal and individual impact	How
DIY Guru (Lim, Tai, Au Yong, Rao & Pan, 2020)	• Educate, • *Promote life-long learning, from user to community experience*	**Problems**: • Need to fix things in the house, while reducing contact with strangers (during covid-19) **Opportunities** in relation to societal and individual impact: • People are trying to develop more skills, be more self-reliant • Forum, validation by experts prior to online publishing	• architectural/ topological/ design patterns, • transfer, • substitute
SafeGather (Lim, Ow, Zaharudin, Kok & Tan, 2020)	• Healthcare, policy and public service	**Problems:** • Underprivileged community lacks support • Inability of NGOs to hold charitable events • Government lacks mechanism to regulate charitable events • **Opportunities**: Link users, NGO and government • Societal impact: More informed tracking, management, inventory planning, distribution based on availability/ needs. • Health impact: Containment of the pandemic • Policy & public service impact: Stronger govt.-public co-op.	• architectural/ topological/ design patterns, • transfer, • substitute • add
Malaysian rail service (Goh, Lee, Mahenderan, Venkatachalam, 2020)	• Policy and public service	**Problem**: Boredom of long train travel **Opportunities**: • To promote long train travel: on-board entertainment, view the train route, view estimated time of arrival, order on-board cuisine, track food order, *toilet availability tracker, emergency assistance for tense situations*.	• architectural/ topological/ design patterns • transfer, add • substitute
 *DIY Guru*	 *SafeGather*	 *Malaysian Rail service*	

4.2 In The Creative Industries

In the creative industries, design has been guided by the quality of solving a real-need, fun, engagement, and sustainability (Lee & Wong, 2015). An example of the spirit of Scratch (fun and experimental), is *Patatap*, designed and developed by a group of graphic design students in Universiti Tunku Abdul Rahman's Faculty of Creative Industries, when the author was a Faculty there (2013-2015). Aimed at reducing stress among students, improving creativity/expression, and improving friend-family relationships, Gan, Na, Ng, Ng, and Ooi (2014) hypothesize that:

- If we can build up teenager's interest on music, teenagers can spend their free time with music.
- If they are interested in music, then they can release their stress through listening to music.

- If we successfully create an attractive advertisement, then those teenagers who do not play instruments, will be attracted to play music.
- If teenagers love to play *Patatap* through the website, then *Patatap* apps will become popular and more people will download it.

To test their hypotheses, an online survey to identify which top three genres are preferred, is carried out. Subsequently, they observe, and confirm observations with a market survey. To make it more interesting and sustainable, they transfer concepts from material science, synthesizers and drumming. Their light-weight equally-sized rollable portable prototype/poster, include a drum-like long wand with a QR code to link to their *Patatap* website, for the promo video (Figure 1). *Patatap* re-represents data representation in the form of small tiles made of different materials and colour. When each tile is hit with the "wand," it produces the desired timbre/pitch. Logic is in the melodic sequence.

Their three-level requirements gathering, and confirmation (design thinking's empathy) are fruitful, with positive responses to the design and artefacts. From their assistive lights source of inspiration (Figure 1b), if *Patatap* has embedded systems, this leaves much room for further connectivity, fun, surprises. Collectively, it may be akin to the 24-season drum, or a playful fun "riot."

a) Different sound effects at the *incredibox* interactive website | b) Assistive lights | c) Patatap poster/tiles | d) Patatap promo video

Figure 1. Their sources of inspiration (a, b) and resulting *Patatap* tiles and promo video (c, d)

5. Discussion and Conclusion

5.1 Design factors more prevalent/important during and post-pandemic: Strategic knowledge, diversity

Brennan and Resnick's (2012) CT approach focuses on computational concepts, computational practice and computational perspectives. ScratchEd defines perspectives as expressing, connecting and wondering. The above examples have been sequenced to project a spectrum in design. All of them are similar in focusing on architectural/topological patterns as the primary design concern, and as the pivot/gateway to possible extensions, for further scalability. These findings concur with Goel's (1997) structure as a representation of strategic knowledge.

Moreover, consistent with Goel's (1997) analogical transfer, the degree of transfer depends on the diversity in the sources of transfer and the designer's knowledge. We also notice that variations in the above examples, mainly include architectural and asset-based refactoring and reuse along a continuum. Findings also concur with Lee, Wong and Lau's (2015), key design factors, i.e., UX and sustainability. This leads us to the second research question.

5.2. Similarity with Lee and Jiang's (2019) CT-HCI predictors

Lee and Jiang's (2019) CT-HCI predictors stress the development of logic and abstraction. The above findings, concur. Data representation, and flow control set the base for abstraction and logic. The designs concur with GBS, GOMS and especially, Goel's (1997) strategic knowledge, ScratchEd's expressing, connecting and wondering characterizations of perspectives, for strategic extensibility and scalability. Future work should include multi-modalities.

5.3 Possible implications in terms of the Interest-Driven Creator theory

Progressive diversity in contexts, and difficulty, are congruent with Cognitive Flexibility Theory (CFT) and Bloom's taxonomy. Information flow, clarity, meaningfulness, user experience and sustainability continue to form suitable assessments. In terms of creativity, findings concur with Kruschitz and Hitz's (2010) analysis of the use of design patterns. Furthermore, all student designs extend associations to aggregation. Since strategic knowledge, extensibility, scalability, refactoring, and permutations are the most important in sustainable reengineering, more focus should be placed on refactoring, as a lean and adaptive framing and creativity mechanism, as exemplified by Scratch.

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