ENCODING COLOUR: CAPTURING RULE-BASED LOGIC IN DESIGN STUDIO

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Abstract

This paper explores the idea of encoding as a way of introducing algorithmic thinking to basic design pedagogy. It gives prominence to positioning the basic logic and attitudes of algorithmic learning of design, rather than simply focuses on utilising the computational devices and tools. This paper examines the integration of computation or algorithmic thinking into a basic design studio in the architecture programme at Universitas Indonesia. The integration is conducted through a colour composing exercise that comprises of four major encoding stages: identifying patterns, rulemaking, colouring-composing, and reflection. The findings from this study demonstrate the use of algorithmic thinking as the primary reason to design colour composition in different ways and complexity. The students can point out some underlying concepts and creative strategies of design computing concerning colour composing. The findings of this study indicate the importance of promoting students' understanding of computation that is not merely tools but more into design reasonings and skills.

Keywords: algorithmic thinking, rule-based logic, design studio, design pedagogy, colour

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Introduction: Digital technologies in design pedagogy

This study explores the process of encoding as a way of learning about algorithmic thinking as part of design pedagogy. The emergence of digital technologies triggers influential changes in architectural theory and practice, leading massive changes in design tools, design methods, to design thinking (Oxman, 2008). The growing impact of the integration of digital technologies brings a challenge for architectural education to consider the computational and cognitive approaches as a foundation for their pedagogy (Oxman, 2008; Özkar, 2007; Stiny, 2001). An appropriate understanding and deployment of digital technology as a way of thinking, particularly algorithmically, can better contextualise and expand the design process (Deamer et al., 2020). Nevertheless, this potential has not been critically articulated often in the design studio as part of architectural education (Akin, 1989). Thus, this paper intends to explore the possibility of introducing algorithmic thinking within the early stage of design learning, particularly by integrating the process of encoding (Hovestadt et al., 2020) into the creative learning process.

Previous attempts at algorithmic learning have been made through the integration of digital media courses into design studios, by providing students with training in software and technical subjects. However, the course's nature often prevents "a deep exploration of design and the theoretical aspects involved" (Schnabel, 2007, p. 237). Some forms integrations are often incorporated into a more advanced design studio where the students already acquired some design skills and knowledge but are mainly limited in the use of digital technologies for representative purposes (Iordanova & De Paoli, 2005). Very often, the learning of digital technology segregates the students' cognitive process of computation and design instead (Kotsopoulos, 2008), resulting in the tendency to see digital technologies merely as tools.

The study highlights that there is a possibility to address digital design thinking beyond the use of digital platforms as tools. As an example, Ostrowska-Wawryniuk et al. (2022) discuss the process of creating an early-stage design course that engages students in translating geometric foundations into parametric models. Since most participating students have no prior knowledge of generative tools, the course was supplied with an analogous initial phase that introduced the idea of parametric and geometrical rules. In this sense, the analogous initial phase provides possibilities for the student to develop analytic thinking and techniques as the basis of computational design, without having to utilise the generative digital tools themselves.

Some attempts to integrate computational knowledge into the studio can be seen in design studio practice by Celani (2004) and Gremmler (2014). Celani (2004) introduces the concept of shape grammar in an advanced design studio, exposing the students to a rule-based logic. However, due to limited exploration of the logic, the students tend to think of the rule as a formal and rigid way of creating (Celani, 2004). Meanwhile, Gremmler (2014) uses colours and computer tools to quickly generate variants of compositions. The exercise exposes students to the generative side of the integration of computational and digital tools in a design studio.

The current design education is often focused on the design outcomes and skills, neglecting the value of competency as a "quality acquired by learner, a potential for reflection and action" (Murphy et al., 2020, para. 6). While digital technical skill is required, we believe that the integration should focus more on the fundamental logic and principles of computational design from the early design studio. This approach ensures that students can fully acquire the cognitive aspects of digital and computational approaches in design. Measuring competence in design practice can only be seen through "knowing where to find it, which specific kind of knowledge to apply in a particular situation, and how to use it when needed" (Oxman, 2004, p. 65).

Integrating computing in learning curricula should emphasise "inquiring, integrating and adapting" (Özkar, 2005, p. 312) towards the principal idea of design. Learning about design computing hence does not necessarily emphasise computational devices in the process. It should instead concentrate on building and developing systematic and algorithmic thinking (Ostrowska-Wawryniuk et al., 2022; Özkar, 2007), especially in architectural design studios. Thus, this paper proposes the process of encoding, which involves the conversion of data from one format to another (Bernhard, 2019) as an approach to encourage rule-based logic as a part of the creative process.

Integrating rule-based logic into the foundation of design learning

An elementary architectural design course, often known as 'basic design studio,' is commonly practised as an introductory and foundational course, posing as a bridge for students to get to know architecture (Harani, 2023). The studio is primarily designed to develop students' comprehension of design reasoning, principles, and skills (Özkar, 2005) to teach students to face problems with expedient foregrounding rather than propose an immediate solution (Colomina et al., 2022). In this way, the students can be encouraged to enquire through research, explorations, exercises, and discussions with tutors or facilitators.

Many basic design studios adopt the pedagogical model of the Bauhaus, in which learning is based upon 'beauty as skilfulness,' where material exercise is done as a simulation to think constructively (Ackermann, 2000). The model of Bauhaus pedagogy poses "bi-polarity" (Oxman, 2008, p. 108), where formal concepts were integrated into skills or crafting-making. This includes learning about "materials and tools and the study of nature, material science, space—colour—composition, construction and representation" (Oxman, 2008, p. 108). The exercises are not mere skill training but more about analytical training in awareness and creativity aimed at authenticity and economical work in craft-making (Ackermann, 2000). With the emergence of new design tools and reasoning alongside digital and computational design, there needs to be a way for studio pedagogy to incorporate the conceptual shift into basic design skills required by students.

The conceptual shift of digital and computational design brings the idea of computing as a way of thinking or reasoning in design. This is not merely mechanical, but it also considers more about the process of visual calculation (Stiny, 2001). This concept requires algorithmic thinking as the primary reasoning to design, in which algorithmic thinking can be defined as "rule-based strategies to solve problems" (Ürey, 2021, p. 57). It also requires a procedural logic, i.e., 'if-then-else' operations, that contains "finite, intelligible, and rational steps that may or may not include computation" (Terzidis, 2006, p. 15).

Encoding as a process of thinking is achieved by integrating meaningful, organised, and elaborating new information with previously acquired information in long-term memory (Schunk, 2012). To represent knowledge in the long term, the association of information structure should be done as a cognitive process (Schunk, 2012). One way to do this is by forming associations between bits of knowledge. This can be done by creating chunks of related information (Miller, 1956), breaking information into parts, and mapping the relationship in-between (Schunk, 2012).

Teaching computing and algorithmic thinking, thus, should involve the process of inquiring, integrating, and adapting the rule-based logic into the formal theoretical base of the design process. The encoding or knowledge acquisition of algorithmic thinking should emphasise the cognitive process of computing a procedural logic rather than following a workflow of some tools. However, to ensure that the information of rule-based logic is stored and retrieved in the long term, the encoding structure should incorporate both cognitive and behavioural processes. This can be acquired through a series of input-output processes of stimuli and creative response, helping the students acquire the procedural knowledge of rule-based logic.

Composing by encoding colour: Overview of learning process

In algorithmic thinking, the designer straightforwardly follows certain rules towards a specific goal (Ruscio & Amabile, 1999). This is done by creating a scripting language or 'textual instruction' that functions to design (Berlinski, 2000). The creation of scripting language or textual instruction in this paper will be called as 'rulemaking.' This paper investigates rulemaking and its design implications in a foundational design studio exercise. In particular, this study examines the learning process in a colour exercise in the Basic Design 1 (BD1) studio for first-semester students of Universitas Indonesia. The learning objectives of this studio are to create various 2D and 3D works based on general principles of design and fine arts. In addition, the students should also master various basic 2D and 3D representation techniques. This includes knowledge regarding composing visual elements of form, colour, texture, modelling, and assembling techniques.

This study proposes an approach to expose students to systematic and algorithmic thinking through a rule-based colour exercise. The exercise utilises the notion of "ordering of colours" (Ackermann, 2000, p. 392) and "systemization of colour" (Ackermann, 2000, p. 399) coined by Ostwald and Kandinsky, respectively, from Bauhaus. These notions attempt to create a harmonic order of colours by making them measurable and systemised. The logic of the colour system introduces its possibility to be used as visual tectonics to design space (Riskiyanto & Anandhita, 2022).

The procedural and algorithmic thinking is incorporated into a basic colour composition exercise that comprises four major stages: identifying patterns, rulemaking, colouring-composing, and reflection (Figure 1). In this exercise, the students were asked to create a colour composition by deciphering a chosen source into a textual instruction or rules. The students were asked to choose a musical sheet or lyrics as the source of their rules. The students then decipher either of those into rules of colour composing based on the patterns they found in their source using their creativity of rulemaking.

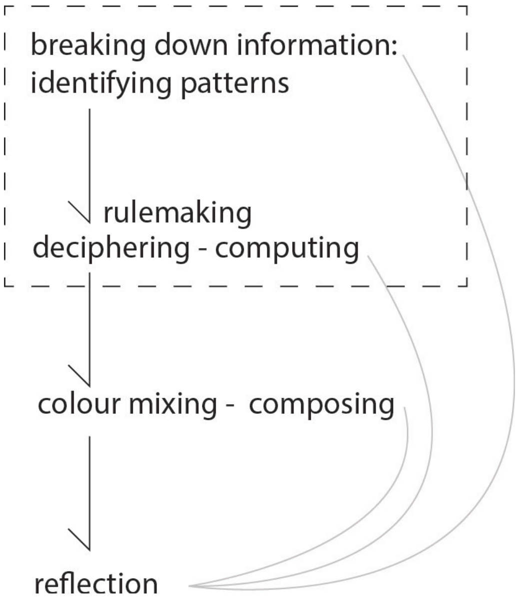

Figure 1. Four stages of colour exercise (Image by authors)

The colour composition was done on A3-sized papers as both in-class and home exercises. The compositions done in class were created on 40 grid squares sized 5 x 5 cm, while the one done as homework was created on 247 grid squares sized 3 x 3 cm. The students were instructed to use poster paint and work within the colour theory. Prior to this exercise, the students participated in a brief workshop regarding colour theory. The knowledge was further examined in this exercise by implementing some colour compositional principles, such as colour values, colour contrast, colour mixing, and colour schemes.

In this exercise, the student becomes a design researcher who learns 'about design' on top of learning 'how to design.' The final part of the exercise was promoting the 'reflective practice' (Schön, 2017) which was evaluated by distributing an online reflection form for students to fill out at the end of the studio week. This reflection stage gave opportunities for the students to reflect on what they had learnt and experienced on particular topics and exercises. This final stage also elaborated their comprehension of conceptual theories and skills during studio activities.

Revealing the encoding process: From rules to composition

This study examines students' knowledge acquisition of rule-based logic and their awareness of its implications in designing a simple composition. The study was conducted through content analysis, using a combination of reflection text and images gathered from the exercise. The analysis attempted to examine personal and complex data (Saginatari & Atmodiwirjo, 2018) that reflect the student's learning process.

The data consisted of images of students' rules and compositions and textual copies of students' reflections. Text analysis of students' reflections was conducted to identify prominent keywords, conceptual topics, and clusters of knowledge gained by the students. For analysis, all students' reflections were translated into English and students' identities were anonymised by using initials. The data was collected at the end of the studio sessions in two forms: images and text. Images of the students' rules and compositions were uploaded into a shared drive, along with their chosen sources. Each student produced a set of rules and three colour composition works. The reflection texts were gathered through the reflection form at the end of the week, where the students were required to write 20–120 words to reflect what they had acquired and experienced from the exercise.

The statements within the reflections were analysed by identifying recurring keywords and concepts that the students associate with rule-based logic. The statements were then further categorised into four major themes. The first theme is the statements reflecting the exercise's general idea as a domain-to-domain transfer. The second theme consists of statements that reflect students' understanding of the logic being used in the exercise. The third theme comprises statements about using rule-based logic in generating variations and patterns. The fourth theme highlights skill sets that the students learnt from the exercise.

In addition, the images of students' rules and compositions were analysed to identify the rulemaking workflow and apparent patterns that the students created. This analysis was also used to corroborate the statements from the students' reflections, especially regarding the third and fourth themes.

Encoding colour as a rule-based logic learning process

The students' reflections show various ideas that the students can comprehend in connection with the rule-based exercise. The following sections will discuss some underlying concepts the students learnt from transforming sources, rulemaking, and colour composing. Some underlying concepts that arise are domain-to-domain transfer; logical, systematic, creative thinking; generating variations; and colouring skills.

Encoding colour as a domain-to-domain transfer

The exercise demonstrates the possibility of learning algorithmic thinking through bridging with another domain. To aid students with acquiring knowledge in rulemaking, this study uses familiar and popular knowledge that students have, which is music. The integration is performed by utilising and associating previously acquired knowledge with new meaningful ones (Schunk, 2012). The process of incorporating is achieved through domain-to-domain transfer. This operation includes selected content being disclosed from the source domain, mediated through a transfer frame, and then incorporated into a target domain (Plowright, 2014). The mediation between the source and target domain in the exercise is conducted by deciphering the source into the rules of composing.

The exercise brief gives students the freedom to choose the source type and specific arrangements they can use in the rulemaking process. Some students note the fact that they can translate or transform the musical source into a colour composition. At the same time, others highlight the rulemaking process, which allows the transformation between different forms to happen, as indicated by the following statements:

> I learnt that music (either from lyrics or musical notes) can be translated into numbers and processed into a colour composition. (Student 1)

> We did a colour rules exercise, transforming a song into a colour composition. (Student 2)

> I also learnt how to transform one art form (music) into a different art form (painting). We should make some rules so the composition of the music can determine the composition of the painting. (Student 3)

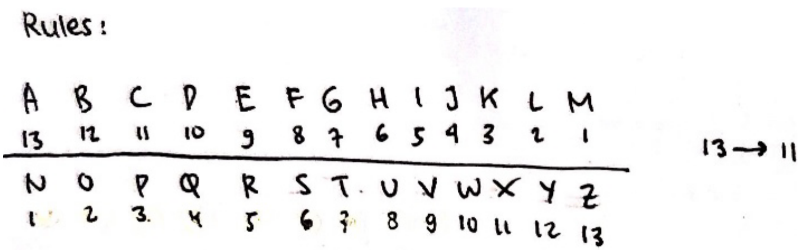

Figure 2. Simple computing to transform letters into number (Image by Thalia Baladraf)

The deciphering process that the students perform can be determined as *domain-to-domain mapping*, which is the process of "moving content from one domain or area of knowledge—... to another area of knowledge" (Plowright, 2014, p. 46). This process can be counted as a breakdown of information and the relationship between different bits of knowledge. In the cases where lyrics are chosen, students deciphered the alphabet into numbers corresponding to a specific colour they chose according to the colour theory. In deciphering this, some did more straightforwardly, while others were created in layers of computation (Figure 2 and Figure 3).

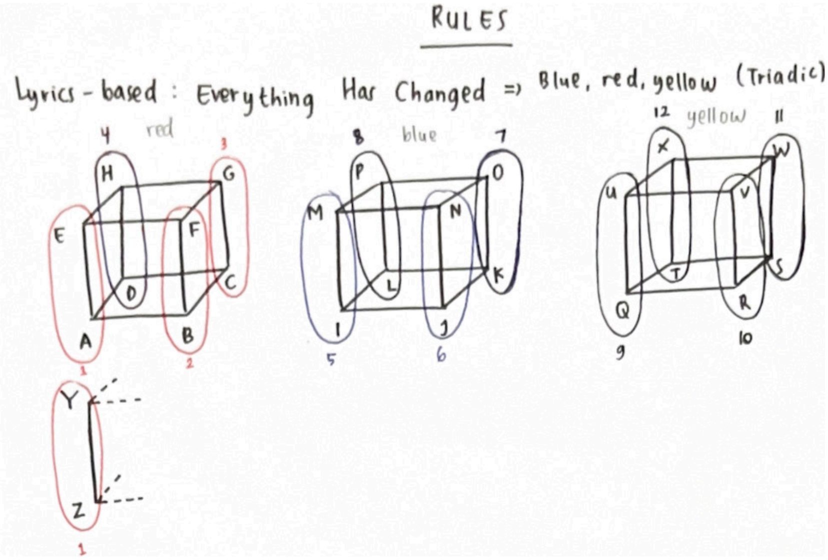

Figure 3. Creative computing of letters into numbers (Image by Joena Salsabila Subrata)

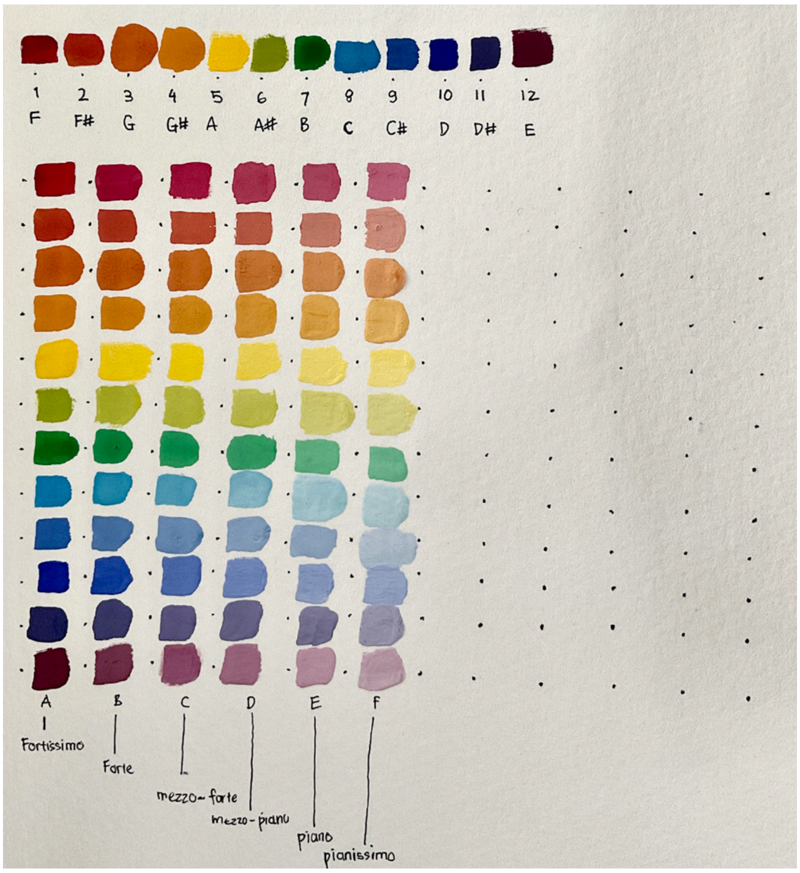

Figure 4. Incorporating musical notes into the colouring rules (Image by Steven Gilberto)

The difference in the *domain-to-domain mapping* process is also apparent in the students who chose musical notes as their sources. Some students straightforwardly translate musical notes into numbers corresponding to scales of colour. Meanwhile, others try to take a more detailed translation by applying sharp and flat notes to the scaling (Figure 4).

Some students also point out that the domain-to-domain transfer through the exercise allows interesting compositions to emerge. A student noted that the compositions represent the song in a different complexity than the colour used.

> Lyrics from a song could be translated by using rules which could produce an interesting colour composition that represents the song. (Student 4)

The students' works and reflections demonstrate various mapping of domain-to-domain transfer that is performed algorithmically. Students could break down information from their chosen sources and creatively incorporate it with a new design process through various ways of deciphering.

Encoding colour as a logical approach to creativity

Using musical sheets or lyrics as the source intrigues students to observe and find the patterns in their musical choices. This also opens the students' minds to a less rigid way of seeing rules as a creative design strategy. Most students note that the cognitive process of encoding colour encompasses three types of thinking: logical, systematic, and creative. The students' reflections below highlight logical and creative thinking:

> I obtained so much knowledge in this session. A few of them are to communicate information from lyrics into a colour composition and train my creativity and logic in rulemaking, especially in the second exercise. (Student 5)

> I feel that this exercise trains my thinking logic. In rulemaking, there are a lot of considerations that need to be thought of so that the rules are interconnected (not perfunctory). Before painting, I need to think about the flow of the grid, etc. (Student 6)

A student highlights the rulemaking process as logical thinking training, achieved through logical consideration in creating interconnected rules to transform lyrics into a colour composition. Meanwhile, another student focused on the concept of *coding* as a logical way to transform letters into colours. On top of logical thinking, these two cases also show how students employ creative thinking in rulemaking. Creative thinking is "how various specific processes are employed or combined" (Ward & Kolomyts, 2010, p. 98). This is shown in their creative ways of transformation, such as translating, coding, and computing.

Figure 5 shows computing as a workaround for translating 26 alphabets in lyrics into 12 colour scales. For the student to be able to put all letters into the twelve colours, they use a basic computation where a two-digit number such as Z (26) will be transformed into another number on the 1–12 scale. According to their rules, the number that corresponds to the letter Y–Z should be timed with each other. Hence, the letter Z will correlate with 12 and be associated with the colour at the end of their scale.

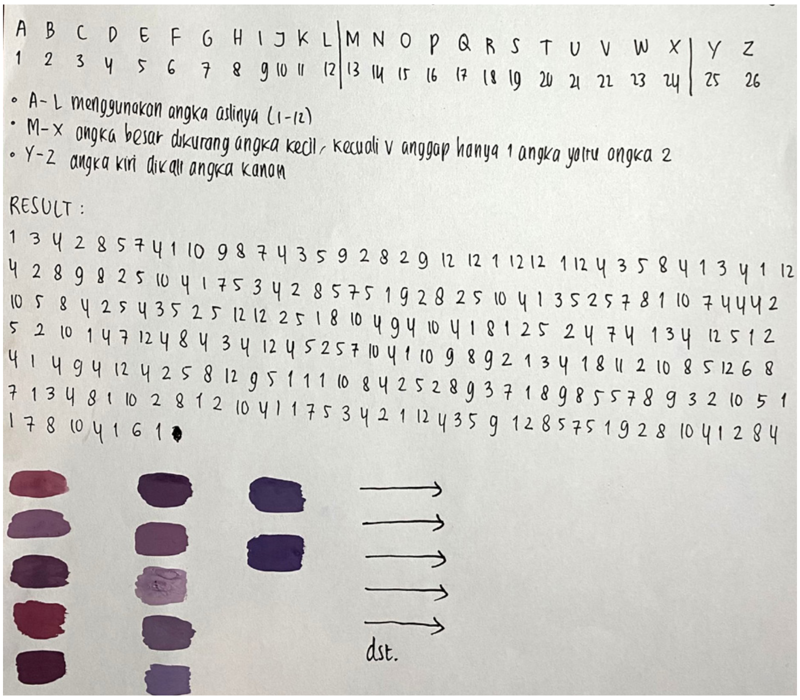

Figure 5. Colour coding of each letter with the number (Image by Sophie Andini)

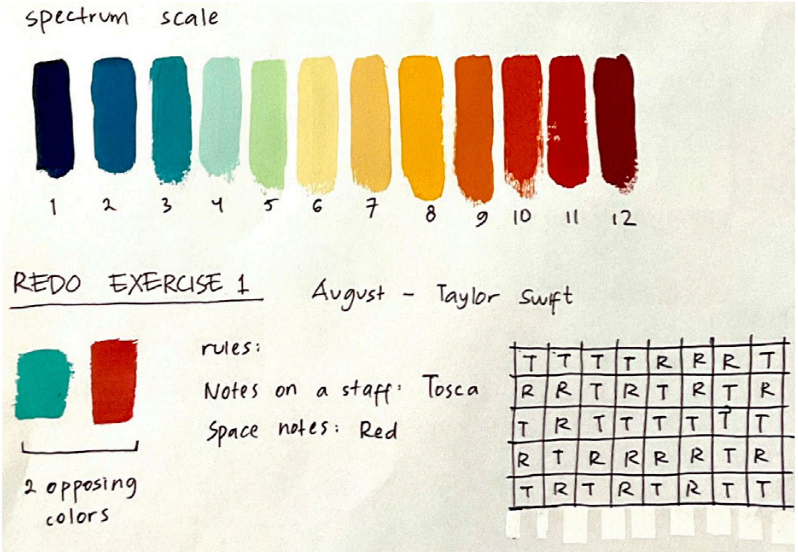

Figure 6. Colour coding with letters assigned to grid (Image by Amaradea Maritza)

Figure 5 and 6 also show different coding methods as a prior process of implementing the rules into a composition. In Figure 5, the student performs coding by translating each letter into numbers according to the sentences. The student further consults this list of translated numbers as the flow in which they will colour their square grids. Meanwhile, Figure 6 shows the coding of the square grids with the initial of their designated colours, which are tosca and red.

> The rule will define the position of colours on the paper and further create a colour composition... I learnt to determine colouring based on opposition rules and be consistent with

the rules that I made... I realised that I needed to be more careful in mixing the colours. Because there will be a drastic difference if there is an error in re-creating the colour, that will affect the colour composition. (Student 7)

Some students also highlight the importance of systematic and procedural thinking throughout the rulemaking and colouring. The statement above shows students' findings of systematic and procedural thinking through three phases: how rules will determine the position of colour, the importance of consistency in implementing the rules, and the effect of inconsistency towards the result.

Encoding colour as a strategy to generate variations and patterns

The goal of this exercise is that the students should be able to design a creative colour composition. The word creative is defined as "the ability to create work that is both novel (i.e., original, unexpected) and appropriate (i.e., useful, adaptive concerning task constraints)" (Sternberg & Lubart, 1999, p. 3). Despite the task constraints, students can create unexpected rules and compositions that reflect a variety of thinking and skills.

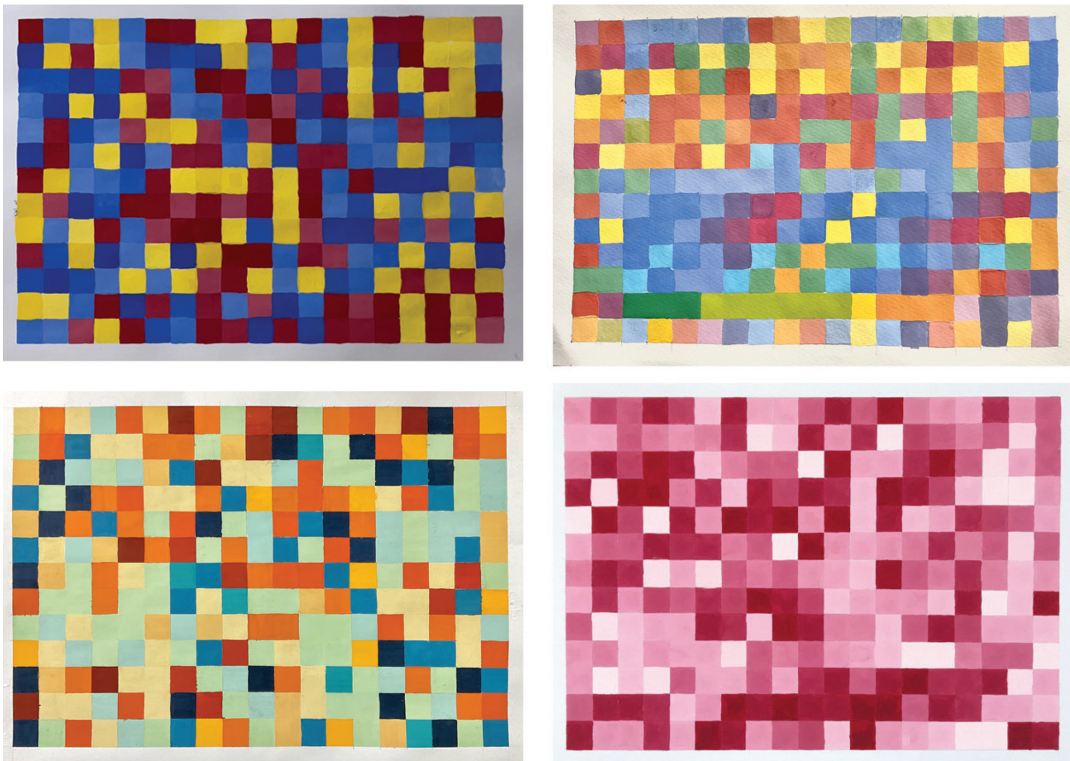

Figure 7. Various colour compositions based on students' defined rules (Images by Joena Salsabila Subrata (top left), Steven Gilberto (top right), Amaradea Maritza (bottom left), Shahnaz Viralahbita (bottom right))

Figure 7 shows the composition generated from students' rules. The figure on the top left illustrates the implementation of rules into a primary colour composition, the top right shows the implementation in rainbow colours, the bottom left shows the implementation in tetradic colours, and the bottom right shows the implementation of 12 scales of red. Because the students use different sources and rules, the result shows variations in the overall composition, patterns, colour depth, etc.

I learnt that there are many rules that I could make only from a song. The possibilities are endless. Because many letters are being used, there will also be many colours that could be composed of. (Student 8)

There are a lot of rules that could emerge according to our creativity which allows many possible forms of outputs. (Student 9)

The students also find that creating rules as a creative process is enjoyable and gives them freedom rather than limiting their creativity. The above reflections indicate that the process allows many possibilities of outcomes to emerge.

I learnt that pop songs and classical songs have many differences; classic songs have a more definite pattern than most pop songs, so I can easily see how the songs sound by just looking at the painting. (Student 10)

There are some differences between the compositions that are made out of binary colours and 12 colours. Such as the complexity of the song where the binary tends to generally represent the song while the 12 colour composition represents the music in a more detailed way. (Student 4)

Some other students highlight that the variation given by the composition could also work as the representation of the song by looking at the generated patterns. Student 10 notes that the pattern could show whether the music is a pop or classic due to their different musical patterns. Meanwhile, Student 4 highlights the differences between a composition that is made out of binary and twelve colours but using the same source and rules.

Encoding and computing in colour mixing

Besides learning how to create and apply rules to colour composition, students also learn about systemic workflow and the importance of accuracy and consistency. This learning is reflected in how they feel it affects the process of colour mixing. Some students note that the rule-based method and the repetitive use of specific colours in their rules train them about measurement, consistency, and appropriateness of paint.

I learnt that it was not as easy as I thought to consistently paint the same tone of colour to finish the overall composition… It needed great consistency to make the gradual changes look smooth. (Student 11)

I learnt various things about colour, especially colour mixing according to the tone in the rules. Turned out that the ratio of primary colours in the process of mixing should be set clearly. (Student 12)

Some students remarked on how they learned about the mixing of different colours in order to create a specific or gradual colour. For example, Student 11 stated that the rules they apply impose the colour to have gradual shades. Hence, they learned how to create different shades of colour by mixing different colours with water. Student 12 also added that they learned about the importance of determining the ratio of primary colours in colour mixing.

> The highlighted part of today's lecture/exercise to me was definitely how hard it is to actually achieve the colours that I wanted... I also learned that the consistency of the paint might affect how the paint dries/ends. (Student 13)

> I recognise that I have to measure the amount of paint that I mix so that I can repeat the process and produce the same output every time. (Student 3)

From these findings, we could see that the students see encoding colour exercise as more than a rule-based practice. The reflection indicates that the students can acquire underlying concepts, logic, and skills from a fundamental colour exercise. The findings further emphasise the capacity of encoding exercise as a medium for students to acquire declarative and procedural knowledge of rule-based logic or algorithmic thinking.

Capturing the logic of encoding process

By incorporating algorithmic thinking into a basic and straightforward design exercise, the design studio can provide a medium for students to develop a fundamental understanding of computing in design. The exercise allows students to encode algorithmic thinking both in cognitive and behavioural ways. This includes the acquisition of knowledge declaratively and procedurally (Schunk, 2012), which is demonstrated by the students' reflections and works.

This finding reflects that the students utilised algorithmic thinking as the primary basis of their colour composition in different ways and at various levels of complexity. This process happens through different rule-based strategies, procedures, or if-then-else operations (Terzidis, 2006). On top of utilising the logic, the students can also point out underlying concepts and strategies they found through reflective practice during the exercise.

The exercises of colour composition were conducted by the students several times. Within this process, they are not only storing the new knowledge but also practising recalling it through procedural means (Schunk, 2012) by going through trials and errors. This process triggers the students to see algorithmic thinking not as a mere rule-based strategy (Ürey, 2021) but also as a systematic procedure (Terzidis, 2006) that directs the outcomes.

In retrospect, the findings also show that the students can see various possibilities of rule-based logic in design, specifically in creating a two-dimensional composition. This exercise shows the algorithmisation of creativity (Olave, 2020) of the students, where they create combinatorial arrangements of colours through well-defined rules or algorithms. The findings also reflect the generation of compositional variants that the students can produce within the constraints of the rules. This process results in students comprehending rules not as a limitation of creativity but rather as a strategy to produce creative variants of outputs.

Alongside this encoding process, the students also learnt some skills concerning colour mixing, especially the importance of colour ratio and consistent workflow. The overall process shows students' ability to demonstrate an interplay between logic and creativity (Harahap et al., 2019) by actively reflecting on the rule-based logic exercise. The logical and systematic knowledge the students gained from the exercise enriches their creative process of composing, supported by the development of skills in creative production.

Conclusion

This study attempted to integrate digital and computational thinking into foundational design pedagogy. This paper demonstrates that the teaching of computing or algorithmic thinking does not solely involve teaching digital and computational tools. Instead, incorporation of algorithmic thinking into the formal theoretical base of the basic design studio ensures that students fully acquire the cognitive aspects of digital and computational approaches in design, defined as encoding or logic capturing in this paper.

Through the inquiry, it can be seen that the students are exposed to creating a basic form of design computation; from pattern identifying, rulemaking, composing, and reflections by integrating algorithmic thinking into the process of design exercise. The findings from the exercises indicate four major themes which are: 1) domain-to-domain transfer; 2) logical creativity; 3) variation and pattern generations; and 4) colour mixing computation. The first theme highlights the deciphering process of sources of material into rules as a form of domain-to-domain transfer. The second theme emphasises logical strategies and the importance of systematic and procedural thinking within a creative exercise. The third theme remarks the ability of rule-based logic to generate variations and patterns. The fourth theme demonstrates colouring skills that are gained from the exercise through computing process, such as measurement, consistency, and the appropriate use of paint.

The findings identified in this study becomes an important contribution of knowledge in further understanding computational thinking and how it can be integrated into learning architecture. The overall learning processes in this colour exercise resulted in students' understanding of computation that is not merely about the technicalities of the tools but more into the acquisition and application of design reasonings and skills. In doing so, it is argued that the student can better comprehend and tailor the use of digital technology for various design needs. Further study of computational thinking in learning architecture becomes necessary, using various means and media. Such understanding becomes a crucial competency for students as future designers to be able to integrate and practise digital and computational design knowledge in a more conscious and controlled way, providing a strong basis for creative design practice.

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