Science Sketchnotes: Techniques and Strategies for Visual Note Taking in Science and Education

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HCI-E MSc Final Project Report 2022
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ABSTRACT
Science sketchnote is a note-taking method that uses visuals, including illustrations, words, labels, etc., to display scientific information that often includes complex processes and concepts for the public audiences to comprehend. Learning with visual materials such as images, graphs and illustrations have been proven effective for learners in learning science. This research investigates the techniques and strategies for sketchnoting in science and education by unpacking the elements of science sketchnoting and compared with general sketchnoting skills. This research also provides a set of further suggestions for the design implication for digital tools that support sketchnoting in science learning contexts.

Author Keywords
Science sketchnote, sketchnote strategies, visual notetaking, HCI, science education

ACM Classification Keywords
H.5.m. *Information interfaces and presentation* (e.g., HCI): Miscellaneous

MSc Contribution Type
Please select from the following contribution types: Empirical, Design, Interaction Techniques, Methodological.

1. INTRODUCTION

A sketchnote is a nonlinear note-taking method that involves listening, synthesizing and visualizing information.[22] It is widely used in various situations, normally in live events such as lectures, talks, or conferences. It can also be used to take notes on contents in books, articles, etc. Sketchnoting requires low fidelity and low complexity of visual output and building the relationships of contents through visual connections such as lines, frames, dividers, or arranging the space on the canvas. [28] This characteristic makes sketchnoting more accessible for people without drawing techniques training. Sketchnoting uses dual modalities (visual, text) that require students to organise, select, and integrate knowledge, all within a context that allows them control over the stimuli, making sketchnoting a potentially valuable instructional technique for learning sciences [1]. Previous research [7,20,29,30,36] has investigated the elements of sketchnoting that provide a big picture of the sketchnoting domain. However, science fields have unique characteristics in terms of contents, logic and application. This research investigates the techniques and strategies specifically for sketchnoting in science and education through unpacking the elements of science sketchnoting. We also compared the difference between general sketchnotes and science sketchnotes to identify better techniques and strategies used in science sketchnoting. Having in-depth conversations with three professional and experienced sketchnoters, we obtained valuable insights into science sketchnote strategies that informed our design suggestions.

To achieve our research goal, we analysed 103 sketchnotes posted online with the thematic analysis method. In this phase, we distilled elements in science sketchnotes and compared them with elements in general sketchnotes. Although both types of sketchnotes share core characteristics of sketchnotes, which as Mike Rohde defined *"rich visual notes created from a mix of handwriting, drawings, hand-drawn typography, shapes, and visual elements like arrows, boxes and lines"* [28], we found that science sketchnotes, which often with more complex and abstract topics, have their unique elements to address these challenges. For example, the use of illustration contains more details and annotations to support the expression. We brought our insights from the analysis to three interviews with three experienced science sketchnoters. We identified five themes of science sketchnoting strategies to address different science sketchnoting tasks or challenges. These tasks are: (1) prepare for sketchnoting, (2) sketch information, (3) Organise Complex/Abstract concepts, (4) Craft Science Illustrations, and (5) Sketch with digital tools. Synthesising our findings from sketchnote analysis and interviews, we introduced design suggestions for the future science sketchnoting digital tools that can support sketchnoters in sketchnoting. These include: (1) building personal visual habits, (2) suggestions for design layout, (3) assist sketching complex illustrations, and (4) Educational Purpose.

MSC HCI-E FINAL PROJECT REPORT
Project report submitted in part fulfilment of the requirements for the degree of Master of Science (Human-Computer Interaction with Ergonomics) in the Faculty of Brain Sciences, University College London, 2022.

This paper is the first in-depth analysis of science sketchnote that investigate sketchnotes in perspectives of HCI and education. The qualitative research outcomes on science sketchnote components and strategies can inform the development of supporting science sketchnoting tools.

In the remainder of the paper, first, we'll introduce the key areas of related work in sketchnoting and education. Next, we present the results of science sketchnote analysis and compare them with general sketchnotes. Then, we will discuss the strategies of sketchnoting science with our learning from interviewing experienced sketchnoters. After this, we will present a series of design suggestions for digital science sketchnoting tools to deal with the challenges and tasks found in science sketchnoting. Finally, I discuss issues that emerged from our study and some directions for future research.

2. BACKGROUND AND RELATED WORK

This part will contain three sections. (1) value of note-taking in education (2) sketchnote in science and education (3) digital tools to support sketchnote in education.

2.1 Value of Notetaking in Education

Note-taking is believed to benefit student learning performance. [11,34] Taking notes improves students' learning and retention in various settings, and the method used by students to take notes can be effectively manipulated through different strategies [34]. Peper and Mayer's research [24,25] showed that taking notes is beneficial for a broader learning outcome because of the assimilative encoding process, such as developing connections between the information presented and what they already know. These processes, including paraphrasing, organising, and elaborating on the material, will facilitate performance if learners take notes [24]. In an exploratory study [10], researchers examined the relationship between note-taking measures and middle school students' future science inquiry success using multilevel analysis. The result of the research revealed that content elaborative notetaking was more effective than content reproductive note-taking, based on the source of the notes taken. Students who took elaborative note-taking that involves deeper processing of content did better in developing causal explanations in the experience scenarios.

From a survey study [8] about students' perspectives on notetaking, there are two main reasons students take notes: the process of note-taking and the product of note-taking. Some students believe that the process of notetaking can help them recall their learning contents. Students also mentioned that taking notes can help them to maintain their attention and understand the structure of the learning materials. Moreover, the notes generated after the note-taking enable them to review afterwards, assisting the learner in recalling. [24] Studies have proved that not only the process of notetaking, but the product of notetaking, the notes, can help learners to identify the learning material. Kiewra et al. [12] found that students who did not attend the lecture but received notes to review performed almost as well as those who studied their own notes. We have already known that the encoding process of notetaking facilitates learning outcomes. Research has found that the other primary function of note-taking—the external storage plays a more critical role as participants scored higher after reviewing notes [3,13,34]. This finding is promising that the value of notetaking can be extended beyond the note-taking process and benefit the note-takers and people who can access their notes.

The advantages of notetaking shown in the previous research have proved that this learning strategy is worth deeper investigating. This research will focus on a specific technique of notetaking — sketchnoting, which display information with combinations of visual images and texts.

2.2 Sketchnoting in Science Education

2.2.1 What is Science Sketchnote?

A sketchnote is a nonlinear note-taking method that involves listening, synthesising and visualising information [22]. It is widely used in various situations, generally in live events such as lectures, talks, or conferences. It can also be used to take notes on contents in books, articles, etc. Sketchnotes have been seen as powerful tools that enable verbal and visual parts of the human brain to work together and create a visual map with rich details [29]. Sketchnoting requires low fidelity and low complexity of graphical output and building the relationships of contents through visual connections such as lines, frames, dividers, or arranging the space on the canvas [28]. This characteristic makes sketchnoting more accessible for people without drawing techniques training. Sketchnoting uses dual modalities (visual, text) that require students to organise, select, and integrate knowledge, all within a context that allows them control over the stimuli, making sketchnoting a potentially valuable instructional technique for learning science [1].

There is no standard definition for science sketchnotes in the literature. Different papers use different terms to discuss, such as sketch, diagram, visual representation, external model, visualisation, illustration, and picture. Like sketchnotes, science sketchnotes usually use a range of sketches, from simple shapes and lines to picture-realistic drawings, to visualise complex information [21]. Compared to sketchnotes which are often drawn in real-time to capture the essence and main points of a talk, video or any other event, science sketchnotes usually include more details and explanations for complex and sometimes abstract science concepts. The differences between sketchnotes and science sketchnotes will be further discussed in this research. In this paper, we embrace an inclusive definition of sketchnotes; that is, we define science sketchnotes broadly as:

Analogue or digital science notes created from a mix of handwriting texts and visual representations, including language, images, and mathematical symbolism, to depict

any types of science and education contents, such as structure, process or relationship, etc.

2.2.2 Sketchnotes in science education

In science, technology, engineering and mathematics (STEM) disciplines, many abstract concepts involve spatial, temporal or even more complexity that is challenging to understand without visualisation. Visual representations help unseen concepts visible and simplify complex information. Therefore, it is critical in science to use visual models to teach, understand, communicate, and develop ideas [26]. According to Pavio's Dual Coding Theory [23], students learn more when using verbal and visual information together than learning with verbal information alone. Mayor's Cognitive theory of multimedia learning [17] states that when individuals combine words and pictures with knowledge can lead to deeper understanding. Science diagrams can enhance learning and communication and are considered an important skill to cultivate among science students. Drawing may lead to more successful learning when students actively select, organise, and integrate information to develop a visual model that represents a mental model [17,26]. Heideman et al. [9] conducted three experiments. They found that sketching helps students master science learning tasks faster, recall learning contents better and improve problem-solving skills, even without further practice sketching technique.

A study that assessed the participants' recall performance found significant effects that drawing can enhance memory across settings [35]. Wamms et al. [35] conducted seven free-recall experiments, and the results showed that participants recall better with the help of drawing. The researchers hypothesised that drawing improves memory by allowing semantic, visual, and motor aspects of memory to be seamlessly integrated. Studies have proved that visual representations drawn by students are helpful in recalling [35], thinking, generating hypotheses, developing predictions, and communicating results [26]. Sketchnotes also encourage students to learn more creatively, strengthen their memories and assist their understandings [32].

However, studies have contradictory results on whether drawing can benefit students' learning performance. [15,18,19] Van Meter and Garner [19]proposed a possible factor that distinguished the difference between those studies that found positive effects of learner-generated drawing notes and those studies the effects were not found. The studies that found significant effects of drawing improved learning outcomes used high-level assessments as post-tests to measure participants' knowledge of systems-level connections. [18,19] On the other hand, studies with less favourable results use lower-level tests such as recognition tests [19]. Quillin and Thomas [26] argued that the expected outcome of scientistic drawing should be the purpose of communicating with others or creating and constructing mental models and knowledge instead of assessing learning outcomes.

In a study conducted with Japanese and American students [11,16], the results showed that students considered using diagrams in notetaking are helpful for them in organising information and making the information easier to retrieve for later use, such as reviews. Most of them included diagrams in the notes to comprehend and learn the contents. However, when constructing explanations of the concept for others, fewer students will use the diagram as a communication tool. The researchers implied that students might lack personal experience using diagrams for communication purposes. Therefore, Manalo et al. [16] further suggested that the critical focus of future research on diagram use in science and engineering education should be investigating methods of promoting diagram use in constructing communicative information for others.

Sketchnotes have a great potential to serve as a communication tool as it supports the acquisition of content area knowledge and improves comprehension [2,7,19]. Fernández-Fontecha et al. [7] adopted a social semiotic perspective to analyse the underlying mechanisms that make complex scientific content accessible. In the study, multimodal strategies, such as reformulating complex content into entities with sketchnotes, can reduce the abstractness of specialised discourses like physics and mathematics through resemiotising meanings from one semiotic system to another. This process also increases viewers' engagement. With science sketchnotes, abstract concepts are translated and communicated using new resources (such as diagrams and other simple schematic drawings) while maintaining resources from the original contents (such as mathematical and symbolic notation), revealing a more concrete understanding for non-specialists. Moreover, sketchnotes are often shared on social media after being made to promote and connect to the speaker and audience [30]. These characteristics make sketchnotes a suitable candidate for social communication.

In our study, we are curious about the elements and strategies of science sketchnotes and how these components are applied in the science field to assist the learning process and demonstrate science concepts.

2.3 Digital tools to support sketchnote in Education

Digital pens and tablets are the most common way to do sketchnoting as digital pens replicate the experience of physical drawing tools better than any other input device [31]. One of the most significant advantages of digital tools is the flexibility with features that allow users to copy, paste, undo, and move things around [6,31]. The digital format of sketchnoting generated by digital tools improves the connectivity and portability of sketchnoting [6]. Sketchnotes can share their works with others and easily access sketchnotes in the devices. Sharing notes is an effective way to synthesise learning [11]. Besides hardware devices such as pens and tablets, the software for sketchnoting also plays a critical role in assisting sketchnoting. Various apps focus on different functions. Some apps, such as GoodNotes,

Notability and OneNote, are designed for general note-taking that support text-based notes and sketchnoting. Some apps, such as Procreate, Sketchbook, and Adobe Fresco, are designed for sketching and drawing and have more options for sketching. For example, users can customise their brush, texture, canvas, and layers preference. EdrawMax is an online tool for making diagrams that can support visual use in various settings. Templates enable users to draw diagrams and build ideas with visual output quickly. Especially, they provide many pre-made science elements, such as body parts diagrams, chemical equation diagrams, mechanic diagram symbols, etc. These are hands-on tools for users unfamiliar with sketching or who want to create diagrams within a movement of drag and release.

Although many digital noting tools support taking notes digitally, most focus on providing flexibility or simulating the experiences of notetaking on paper. In our research, we want to explore the potential of digital tools that leverage the efficiency and effectiveness of the science sketchnoting process.

3. STUDY METHODOLOGY

We use a mixed-method approach to understand sketchnoters' strategies when learning science content. Firstly, the thematic analysis method is used to analyse science sketchnotes posted on Instagram and Pinterest. This research aims to analyse science sketchnotes until systematic coding and analysis saturation is reached. The patterns of sketchnoting in learning science are expected to emerge after the coding process. To better understand the strategies and experiences of sketchnoters, the researcher will conduct six to eight semi-structured interviews with experienced sketchnoters based on the outcome of the thematic analysis to dive deeper into the technique and strategies for sketchnoting in science.

Phase 1: Corpus

We created a corpus of images posted under the keywords search results of Pinterest. The keywords were science sketchnotes, science notes, physic notes, biology notes, and chemistry notes. The image recommended by the system based on the search history was also included. We excluded pictures that did not show actual science sketchnotes, were done for commercial purposes, were of deficient quality, or were not showing the whole page of the sketchnote. This query for the dataset was performed before the beginning of the analysis.

One hundred three sketchnotes were included in our corpus after low-level open coding was conducted and included sketches from the dataset until saturation of codes was reached. These codes were iteratively refined via multiple discussions with the supervisor. By the end of this phase, the codes had been refined (merging, renaming, adding, and grouping), as well as the overall themes. Our corpus might not capture specific codes, as with any qualitative analysis.

Phase 2: Interviews

To complement our higher-level analysis of sketchnotes, we conducted three follow-up semi-structured interviews with three experienced sketchnoters (3f; one lives in Brisbane, Australia, one lives in Los Angeles, USA, and one lives in Seattle, USA; sketchnoting experience 3-20 years) from our corpus (1 to 3 of the sketchnotes in our corpus were created by the participants) to gain a deeper understanding of their science sketchnoting processes and design rationales. The questions for the semi-structured interviews were informed by the analysis of the sketchnote corpus to follow up on decisions and strategies — for example, how they structure layouts, how they create science diagrams and illustrations, how they select contents, what the processes for sketchnoting like, or how they deal with challenges in sketchnoting science.

Participants used different interview methods according to their preferences (two via video call and one interview conducted as an email conversation thread and document). Still, our process of conducting the semi-structured interviews remained consistent across participants, with a core set of predefined questions and follow-up with individualised questions derived from participants' responses. Transcriptions of the interview were analysed in correlation with the dimensions and components of the design space from Phase 1. Our institution's ethics board approved this study.

4. COMPARISON WITH GENERAL SKETCHNOTE COMPONENTS

This section describes the components found in science sketchnote. In the first part, we compare the features of science sketchnotes with the sketchnote components found by Zheng et al. [36]. We follow the categories in that paper: content, layout, structuring elements and visual styling. For each component, we highlight the differences between sketchnotes in general and science sketchnote by noting the (number) of sketchnote featuring them in both kinds of sketchnotes and discuss the possible reasons that make them different. In this paper, we analyse a corpus with 113 sketchnotes, and Zheng et al. used 103 sketchnotes to analyse sketchnote components.

In the second part, we extract some unique components in science sketchnotes. These components are recognised because they are essential in depicting science content or organising science-related information while sketchnoting. We provide examples of sketchnotes, and each example can be referred to as specific sketchnotes through their #ids. Note that the corpus and coding are available in the supplemental material and online at: https://www.notion.so/7285d3efa1a94fba8037e62da1241b35?v=3c3420ae919b45e286d87dde0a476168

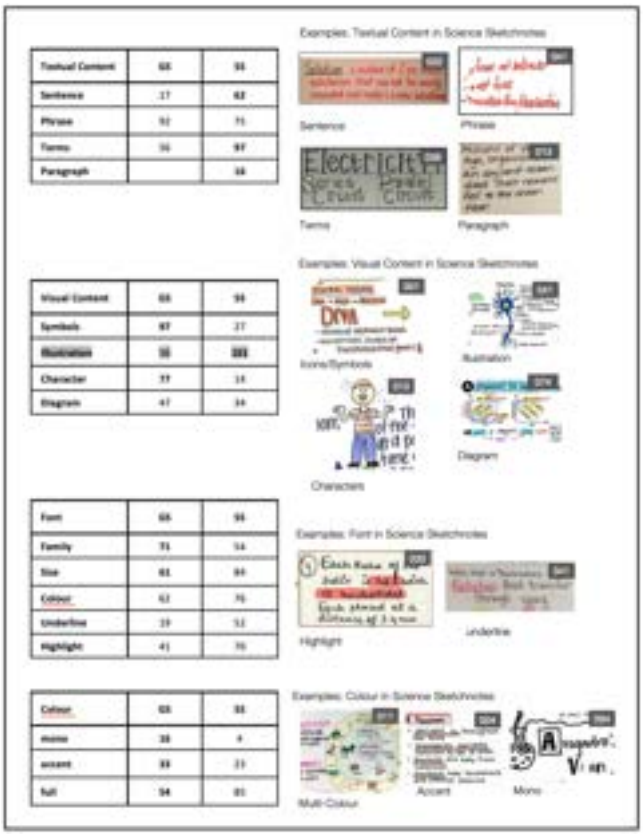

Figure 1: General Sketchnotes vs Science Sketchnotes (Part A)

Figure 2: General Sketchnotes vs Science Sketchnotes (Part B)

4.1 Content

This component describes how textual and visual contents are presented in the sketchnote.

We found it very different how science sketchnotes display information compared to general sketchnotes.

Textual content. Textual content is one of the essential elements of educational sketchnote. Typically, sketchnotes contain highlighted information and less detailed information [5]. In our corpus, we also found that science sketchnotes have a more verbose form than general sketchnote. Compared to general sketchnote that use more catchphrases and terms instead of fully formed sentences, science sketchnotes use paragraphs (16) that consist of more than one sentence and more sentences (62) to capture topic concepts, and information and explanations. The reason for heavier text content in science sketchnotes might attribute to the educational purpose of science sketchnotes. Paragraphs and sentences enable details to be better described in complex concepts (#30, #43) and can be used to state the premise or background knowledge for the learning material (#20, #105).

In terms of font style, there is no difference in both kinds of sketchnotes. **Font family, font size** and **font colour** are used to emphasise and group textual content. However, we found more **highlights and underline** used in science sketchnotes (122 in science sketchnotes and 60 in general sketchnotes). Likely because science sketchnotes are often used in educational contexts, and learners often use them for memorising knowledge from the class.

Visual content. Images, illustrations, figures, diagrams, icons, symbols, and all kinds of visual imagery in the sketchnote make sketchnotes different from traditional written notes. Visual content represents how noters use visual imagery and graphical content to supplement the text[36] and convey information. We found a very different pattern in using visual content in science sketchnotes. (Table or figure here) In science sketchnotes, the uses of icons and symbols (27) and characters (14) are far less than in general sketchnotes (97 icons and symbols and 77 characters in general sketchnotes). The possible reason would be that icons and symbols are not used to represent key concepts or main contents, such as hearts, stars, and smartphones.

On the other hand, science sketchnotes use more illustrations (101) than general sketchnotes (56 illustrations in general sketchnotes). We further broke it into five illustration categories to look deeper into the difference. Five categories are included under this theme: illustrations for an abstract concept, illustrations for structure, magnify, illustrations for mechanism, and text visualisation.

Illustrations for an abstract concept. Many concepts in science are abstract and invisible. For example, instead of using lengthy text to explain Newton's law of motion, visualising the relationship between the moving object and the force acting on it could be a more straightforward way to understand the mechanism. 44 out of 101 sketchnotes with illustrations use schematics to express abstract theories (#080, #083) or to visualise the invisible concept, such as

DNA structure or chemical structure (#037, #111). Even though illustrations have visualised abstract concepts, text annotations (88) are commonly used to complement abstract concepts (#042, #081).

Illustrations for structure. Some subjects, like engineering and biology, depend on illustration to describe the ideas of structures. For example, in biology, it is essential to draw a schematic for cells or the digestive system in the human body to understand and communicate the concept with others. In our corpus, 41 out of 101 sketchnotes with illustrations use schematics to depict the structures (#003, #018, #057). Besides, illustrations are also used to visualise the theoretical structure, such as hierarchy (#011). Moreover, like illustrations used for an abstract concept, when illustrations are used for describing the structures, it is usually along with annotations (37 out of 41) to explain the details in the figures (#003, #018, #059).

Magnify. In addition to using text to annotate the illustration, one technique found in the illustrations is to **magnify** (11) a specific part of the image. With this zoom-in effect, more details can be depicted in a small part of the image. (#3, #17, #100) This technique can also be used to emphasise particular areas in the illustrations (#62) (Figure3).

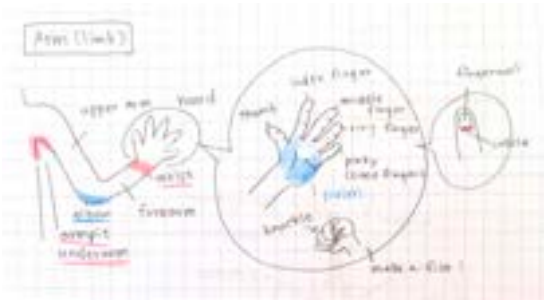

Figure 3: Example of illustrating magnify effect in science sketchnotes (Sketchnote provided by participant 1)

Mechanism. (34) Using diagrams allows noters to visualise processes and things that are real but invisible to the naked eye, such as the way rays of light interact or the change of moon and sun.[4] Mechanisms, such as circulation, force, changes, etc., rely on noters to draw out the process and relationship in the mechanism to demonstrate the concept. The mechanism usually involves complex issues, such as process (#17, #45) that are shown through arrows (14) and breakdown illustrations (8).

Visualise text. (18) Some illustrations in the sketchnotes are used to visualise the text content and do not add any newer information to the sketchnote through the illustration. These kinds of illustrations are commonly along with a relatively heavier text or as a decoration that chooses some keywords to draw the symbols (7).

4.2 Structuring Elements

Layout. The layout is how sketchnoters organise the design space and is a road map of the sketchnote. [20] There are four layouts mentioned in the paper by Zheng and her colleagues: freeform, grid, radial and linear. In the article, the freeform layout is the most common type in sketchnotes far more than the other three types. [36] However, in science sketchnotes, grid (75) is the most used layout. Likely due to the requirement of reading order in educational sketchnotes that needs a higher level of structure. Another reason might be that in our corpus, most of the sketchnotes might not be the real-time sketchnotes that take under time pressure. Therefore, noters have adequate time to consider the layout of the sketchnotes and plan it before sketching.

Grouping. There are more grouping elements used in the science sketchnotes. The use of containers (68), headers (86), and List (91) is commonly used to group content in higher-level entities. As discussed in the layout section, this is probably due to the need and tendency to be more structural in science sketchnotes. Grouping is also a straightforward way to organise complex information. Interestingly, text formatting by list is highly used in almost every science sketchnotes in our corpus compared to only half in the general sketchnotes corpus. This is likely due to the heavy content under one topic, and using a list is a way to break down lengthy texts and complex information to make it more readable and understandable.

4.3 Visual Styling

Noters use different strategies for drawing attention and constructing hierarchy. Hierarchy helps noters and readers to capture the importance of the sketchnotes. [28] Text styling and colour are commonly used to build hierarchy. Regarding colour usage, science sketchnotes use a more full-colour palette (85), which has no clear thematic association with content compared to general sketchnotes. The reason may be that science sketchnotes use more illustrations to demonstrate complex concepts.

Regarding the text styling, there is not much difference between the use of **font family** (54), **font size** (84) and **font colour** (76). However, science sketchnotes use more **highlights or borders** (52) and **underline** (70) to draw attention. This might relate to the more verbose form of science sketchnotes. Highlighting and underlining is an intuitive way to highlight the keywords from the paragraphs and sentences.

5. SCIENCE SKETCHNOTE COMPONENTS

This section will describe the components found in science sketchnotes. These components help build science sketchnotes and did not find in general sketchnotes.

Annotations. Annotations (102) for illustrations and texts are commonly found in the science sketchnotes. In illustrations, it is usually used for literalising drawings to support understanding (#18, #59). In our corpus, almost all graphics use annotation to supplement the figure (88 out of 101 sketchnotes with illustrations). For example, in sketchnotes about the refraction of lights (#42), annotations are used to explain the meaning of the arrows and angles. Participant 1 also provided another example from one of her

works (Figure 4). In this example, annotations can be used not only to describe the term of the nervous system but also used for categorising and explaining the mechanism of nerve conduction. The Annotations are also used to complement the textual content to give background knowledge or missing details. Annotations are also found in the parts of the textual content. The **annotations for text** (62) break the boundaries of the text area and expand the writing space (#47, #114). For example, in (Figure 5), more texts are used to supplement the concept of "transcription" in DNA.

Figure 4: Example of using annotation for illustrations in the science sketchnotes. (Sketchnote provided by participant 1)

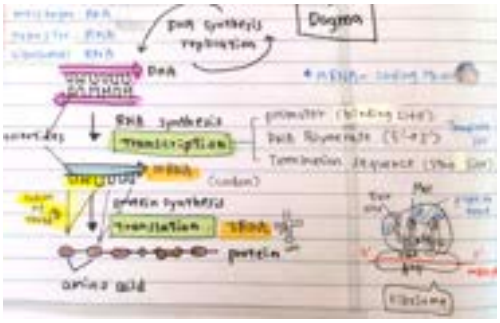

Figure 5: Example of using annotations for text contents in science sketchnotes. (Sketchnote provided by participant 1)

Comparison. Comparison (25) chart and table are used in the science sketchnotes to compare two concepts or within one concept under different conditions (#021, #077). Comparison helps clarify the difference between two or more similar terms or confusing concepts (#010, #036). We found that comparisons are usually organised with tables or grid layouts (Figure 6) so that the information is more readable, and the differences are more obviously shown with these kinds of arrangements (#018, #067).

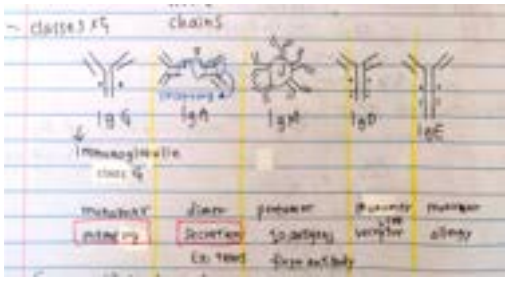

Figure 6: Example of comparisons in science sketchnotes (Sketchnote provided by participant 1)

Scientific diagram. (30) Scientific diagrams, such as statistic graphics and data visualisations, are schematic representations of scientific facts. Scientific knowledge is hard to be conveyed without diagrams and diagrammatic representation [14]. The combination of language and picture symbolism breaks down the traditional boundaries between language and image and makes diagrams unique [14]. These kinds of diagrams may be generated by noters actively synthesising the information (#029, #074). Another advantage of the scientific diagram is that it can provide readers with an overview of scientific facts (#025, #085).

Mathematical Greek and Symbols. (39) Mathematical Greek and symbols are highly used in science subjects to form equations and represent specific scientific meanings or values (#19, #31). These symbols are not shown on the keyboard, and the structures are complex, so handwriting is simpler and more intuitive than typing on the computer.

Stickers. Stickers (10) refer to sketchnoters cutting off things from other resources or documents and sticking them on the analogue sketchnote with stickers, tapes or glue instead of drawing by themselves. (#008, #090, #101) This is used to complement the sketchnotes or expand the design space. We conjecture that these augmented notes might come from their teachers' supplemented learning materials given to the sketchnoters. Stickers can be seen as a time-saving and efficient way to add new information on analogue sketchnotes.

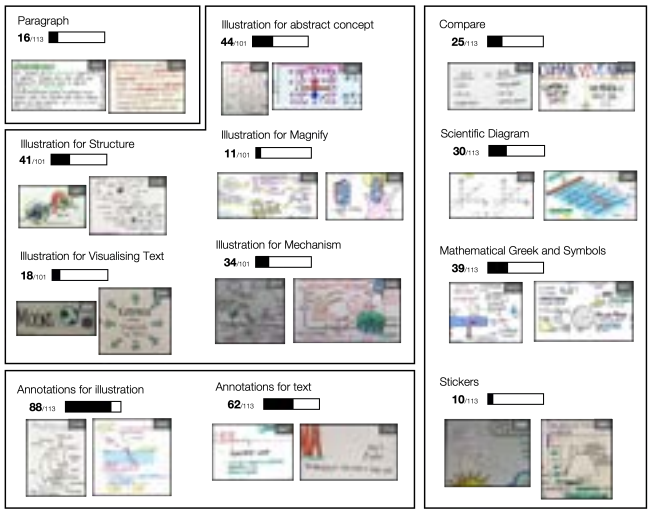

Figure 7: Science sketchnote components (See "List of Sketchnotes" for credits and links")

6. SCIENCE SKETCHNOTE STRATEGIES

In this section, we describe the authoring strategies sketchnoters used to record and communicate content in science sketchnotes. This section discusses how science sketchnotes (Sec. 4 and 5) can capture ideas, emphasise key concepts, provide narratives, and create a sense of cohesion, readable, and visually appealing content. We also outline

strategies that sketchnoters employ to cope with the challenges while doing sketchnotes.

6.1 Prepare for sketchnoting

Sketchnoting involves a series of mental works that includes synthesising contents and structuring design space. These kinds of works require higher cognition capability, so it is better for sketchnoters to have a mental picture of what they will sketch before starting sketching. *"The first thing I will do is to plan, plan what I want to sketch."* (P1)

Outlining the learning materials is one of the most important things to do before starting. "I *will first get familiar with the content and make sure that I have understood, for example, the process of gene duplication. I will outline several points that I want to put into the notes and think of the layout."* (P1) An outline includes a list of main topics, points and key illustrations. This preparation gives sketchnoters a mental roadmap and helps them to prepare for the next step of sketchnote. *"I usually create a small sketchnote of the title of the discussion/talk/event to help anchor the rest of the information that I then sketchnote out live."* (P3) The outline is helpful for sketchnoters to structure the layout, especially when the sketchnote is done on a piece of paper instead of a tablet. *"It is more difficult to redo the notes on the paper, so better with a plan in mind."* (P1). Under live drawing conditions, reviewing the agenda of the event can help sketchnoters to anchor throughout the talk. "*review the workshop agenda in advance of the event so I'm familiar with how the event will be carried out timewise/topics etc. And draw up ideas of each presentation/discussion with some key imagery that I can use as 'quick reference guide' throughout the event."* (P3)

Dealing with unfamiliar scientific knowledge. It is a common situation that sketchnoter take notes for the contents that are unfamiliar to them. *"Most of the science sketchnote work I do is on unfamiliar information, which I think is the best way to create visual stories so that you as the sketchnoter do not include your own personal bias into the sketchnotes."* (P3) In this case, sketchnoters will read or search for materials that can supplement their lack of related background knowledge. For example, one participant mentioned, "*I will try to search for the simplified version to help my comprehension. This is also helpful for me to do the drawing later as you won't want your sketch too complex or inaccurate."* (P1)

Searching for inspiration. As the topics are sometimes unfamiliar to users, they will refer to other material before sketching and see how people demonstrate the same topic with visuals. *"I will google the terms and build my material library."* (P1) Similar strategy is used by another participant. *"I will often do a Google search of the presenter or …to get a better understanding of the topic and associated imagery, so I am able to quickly capture and convey the information live as a sketchnote."* (P3)

6.2 Sketching information

Sketchnote aims to capture the key concepts and synthesise important ideas in a visual form. There are many strategies that sketchnoters use to sketchnote. Some of them are consistent with the finding from the research of Zheng et. al.[36], for example, the use of text to show hierarchy and the use of visuals to illustrate complex concepts. On the other hand, we also found different strategies between these two different kinds of sketchnoting. For example, in science sketchnote, the text is not as concise as in general sketchnote. To demonstrate complex and abstract ideas, science sketchnotes use relatively heavier text to make sure that the idea is conveyed to the audience. In this session, we reveal some common strategies in science sketchnoting.

The layout of sketchnotes. Our participants mentioned that they usually spend time considering the layout of the sketchnote. *"Deciding an appropriate layout is still challenging to me"* (P2). Layout of a sketchnote is not just related to the visual aesthetic but also the logic of the presentation and synthesis. *"it required a certain amount of practice, with more and more sketch experience, you will have an idea of layout styles for different contexts."* (P1) The layout of the science sketchnotes also depends on the time and the amount of the information. *"the longer the time, the more space I allow to capture the information visually."* (P3)

Under the live drawing, the sketchnoters will choose a more structured layout due to the time restrictions. *"I usually lay out the information based on a logical format, such as intro, discussion and conclusions."* (P3) If the topic of the presentation has a clear structure, for example, talking about a process of a phenomenon, describing a biological cycle, or discussing around an idea (Figure 8), sketchnoters can more easily to lay out with a flow or a centred image.

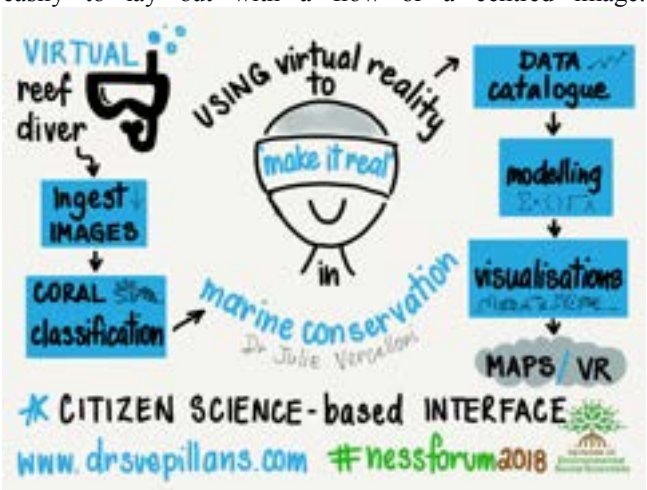

Figure 8: Example of the layout strategy (Sketchnote provided by Dr Sue Pillans www.drsuepillans.com)

Closer relationships between text and visual in science sketchnotes compared to general sketchnotes. Instead of independently existing in the sketchnote, Texts in science sketchnote rely on visual elements to visualise the idea that can enhance understanding, while visual elements in science

sketchnotes rely on text to supplement details. *"I will write some sentences around the illustrations because it is usually quite hard to understand the concept with pictures only."* (P1). Therefore, the text usage in science sketchnote is hard to be too simple and usually includes longer sentences or even paragraphs.

Prioritising information. Sketchnotes is used to capture key points and information in events, workshops, topics, conference, lectures etc. Sketchnoters need to decide which information to capture in the sketchnote and make present the information hierarchy visually. Catching the main topic and the subtopic of a concept while reviewing the material is one way to prioritise information when sketching without time pressure. If the sketchnote is done during a live event, sketchnoters will pay attention to how the speaker talks and find out what the speaker emphasises. *"I listen for key messages/information, repeated messages and even listen to how the person is speaking as their voice may give more emphasis to certain aspects of their talk/discussion."* (P3)

Comparison and differentiate concepts under the same topic. In science sketchnotes, synthesising information with similar concepts is often found. Tables are considered an effective way to organise large amounts of data and clarify easily misunderstood concepts. *"I like drawing tables to synthesise learning contents; it is very straightforward to draw and very flexible to make adjustments."* (P1). Besides, highlighting and colour usage are also common methods to outline the difference in sketchnotes. *"I will use two different colours here to show that these two terms are under the same concept and these two are different."* (P1)

6.3 Organise Complex/Abstract Concept

Science sketchnotes often involve abstract and complex concepts that need more strategies to deal with. Sketchnotes take advantage of visualising ideas compared to traditional notes that consist mainly of texts. Sketchnoters develop strategies to present complex and abstract concepts that are useful to novices in sketchnoting.

Identify main topics and sub-topics. Breaking down a big concept into many small sub-topics clarifies complex concepts. *"Practising breaking down big ideas, whenever I receive new concepts, I will try to break them into small pieces. I always find them (abstract and complex concepts) much more readable and understandable by doing so."* (P2). Participant also mentioned that *"even if the concepts are still vague for me, it is very helpful to understand them piece by piece."* (P1)

Defining the layout of the sketchnote. Choosing a layout for the sketchnote depends on the areas of subjects, numbers of learning points and relationships between topics. For example, for biology, illustration is essential when describing the structure of an animal's body. In this case, centred the image in the middle of the canvas or just making sure that there is space for annotation around the figure is important. Grid is also a common layout for content with more than one point. *"If the figures are more important than the text description, I will choose the horizontal layout. If the figures only take up a relatively small space, I will use a vertical layout that makes sure I have more space to list my points with words."* (P1)

Learn from others. *"I watched other people sketching the same topic when I've tried to sketch by myself but can't find a way to do so."* (P1). One recommended solution is to watch experts in that field elaborate on the concept and learn from them. Since they are professionals, they know better how to deliver the knowledge to others with complete understanding. This technique is also recommended to new sketchnoters to practice sketchnoting by seeing how others do it.

More images and words to support abstract concepts. Sketchnotes is a good way to capture abstract concept as it uses images to display information and can add labels, arrows, banners and many kinds of visual cues to explicit the concept. "*more abstract information may require more imagery (vs words) or more directional visual cues to display the information."* (P3)

Using annotation is another effective way to assist the presentation of abstract and complex concepts. Annotation can be used to supplement ideas that are hard to visualise. In our analysis of science sketchnotes, we found that illustrations often come with annotations. *"…add annotation, it is okay to write down what you think that will help (the) reader comprehend your content, to be honest, I rely much on it."* (P2). Using annotation also release sketchnoters from the stress that they need to have excellent sketching skill to do sketchnoting.

6.4 Crafting Science Illustrations

Illustrations are the most critical element in science sketchnoting. As science is a broad concept that covers many professional fields, illustration in science sketchnotes also involves many different kinds. Therefore, strategies to cope with variability are needed.

Building sketch library. As sketchnotes are used to capture ideas under time pressure, having a collection of sketch elements that sketchnoters can retrieve anytime when needed can faster the sketchnoting process. *"This is a useful tool so you can 'draw upon' imagery quickly. Developing your own sketchnote 'toolkit' of icons, templates and visual cues is the best way to 'shortcut' sketchnotes."* (P3). Participant 3 further stated that a visual sketch library is one of the essential elements of science sketchnote.

Make sure of the accuracy. As science is about being accurate and searching for the explanation of scientific phenomena, visual images can help to lay out information and ease the complexity of the content. Therefore, the image and the corresponding messages must convey the most accurate information. *"I create scientific diagrams by ensuring the science elements I draw out are accurate, and my labelling and direction of the content are easy to read*

and for the eye to follow." (P3). However, the participant mentioned that this is a challenge of science sketchnoting, as sketchnoters are not an expert in that particular scientific field. *"However, you don't need to be an expert in any particular science to create great and accurate sketchnotes. I think each sketchnoter has their own unique abilities (listening, interpreting, analysing, synthesis, translating skills) and overcome the challenges with experience and practice."* (P3)

Refer to other materials to draw the image. Sometimes illustrations in science sketchnote require a higher level of preciseness. *"to sketch the structure of a cell, I need to consider the size of different components in actual ratio; to draw the mechanism of nerve conduction, I need to take care of every detail because this is science facts, needs to be true."* (P1) In this case, sketchnoters will have some references to ensure the sketches are done correctly.

On the other hand, sometimes the problem is not the preciseness of the illustrations but how to simplify complex ideas. *"Like muscle tissue, very complex. The textbook provides every detail of the tissue, but not all of them are needed to learn this chapter. I will google to get some ideas to simplify it."* (P1)

Shadowing others' illustrations is an efficient way to learn how to create your sketch. *"I practice (my)sketching skill by shadowing others' sketches. For me, this is an effective way to build the concept into my mind."* (P2). *"I will follow others' steps of sketching."* (P1). This technique is related to building the sketch library. The more sketch accumulated, the easier the process would be.

Illustrate details with purpose. Illustration and scientific diagrams in science sketchnotes often play an important role in demonstrating the content. Therefore, it is better if the key point of the illustration can be clearly identified. *"of cause, you can draw as delicate as you want, but it should depend on the purpose of your sketchnotes. If it is for conversation with the public, then the level of craftsmanship can be higher, but if it is for learning purposes, I won't spend too much time on drawing beautifully." (P2)*

Aesthetics vs authenticity. It could happen that if you want to achieve aesthetics, you might sacrifice some extent of authenticity. However, in science sketchnote with educational purposes, illustrating facts is relatively more important than illustrating a beautiful artwork. *"be aware of putting the cart before the house."* (P1) *"you can focus on visual beauty, but under the premise of conveying the truth."* (P2)

6.5 Sketching with digital tools

As digital pens excel at replicating the experience of physical drawing tools, pen-and-tablet combinations are widely used for creating digital sketchnoting.[31] Participants pointed out strategies that are specifically for sketching with digital tools.

Adjust the sketchnote layout flexibly. Digital tool allows sketchnoters easily correct mistakes with undo feature, redo repeated elements with copy and paste, and moves things around freely to rearrange the layout. Two of the participants mentioned that flexibility gives them the freedom to adjust almost anything when needed. *"One of the reasons that I switched from paper to iPad is that it is very flexible, I saved a lot of time (because) I don't need to plan too much ahead. I can be more creative."* (P2)

Use sources from the internet. One advantage of digital tools is that sketchnoters can easily add non-drawing materials such as images and stickers from outside sources. *"sometimes, I will just screenshot and paste on it."* (P1) Participants also mentioned that if the image is too complex to draw or not possible to draw by the sketchnoter, for example, an ultrasound photo or a QR code, using an image from the internet is an alternative way.

Redirect readers from sketchnotes to more information. Sketchnoters can provide access to supplemental information not shown in the sketchnote by inserting hyperlinks without taking up the design space of the sketchnote. This is useful as scientific topics usually require a certain extent of background knowledge or are closely related to another topic. *"I will put a link for a more detailed explanation on the website for reference in case the information I put in the sketchnote is not enough for understanding."* (P1)

7. IMPLICATIONS FOR DESIGNING DIGITAL SCIENCE SKETCHNOTING TOOLS

From our analysis, we propose a series of design suggestions for digital science sketchnoting tools derived from our research.

7.1 Building personal visual habits

For sketchnoters, developing their sketchnoting styles or patterns is an efficient way to leverage sketchnoting skills. *"I sketch quicker after several years of practice because I've had my own style, I know what to draw and how to draw."* (P2) *"it became automatically for me, like, I used two colours for annotation, I chose vertical grid layout for topics with more than three points…" (P2)*

Copy the formatting form and apply it to another. As sketchnoters have a personal visual style, patterns will be repeated across sketchnotes. This kind of formatting copy feature has existed in office software such as Microsoft Word and PowerPoint and design tools such as Figma and Adobe Illustration. We can imagine a sketchnoting tool that can copy the format, for example, the width and colour of the brush, so that the user can quickly sketch the content without spending time on setting the brush.

Digital pencil box. This is a follow-up idea to the formatting copy suggestion. If the format of the sketch can be copied, it would be helpful to be able to save it for the next sketching. *"When I was sketching in my notebook, all the pens I need is in my pencil box, about 10 pens, but now there are so many*

choices in my iPad (refer to the software that the participant used for digital sketch) to be honest, I only use a few of them." (P2) The pen settings can be further named with their purposes so that users can easily identify and apply them immediately. *"It would be great if I could save brushes that I use the most. I have my preferred settings for titles, for annotations and…just like I always go for that black pen for signing documents and use that blue pen to leave notes on the desk."* (P1)

Personal sketch library. In section 6.4, we discussed the strategies that sketchnoters took when crafting science illustrations. Building a sketch library enables noters to refer to their own experience when developing sketch skills. Especially in science, many illustrations include complex details that take time to get familiar with. This library is also helpful for sketchnoters to develop their visual style and visual cohesion.

7.2 Suggestions for design layout

System suggestions for choosing sketchnoting layout. Learning from our participants, the layout is one of the most difficult parts of learning sketchnote. (Section 6.2) It requires sketchnoters' experience. One solution is to introduce a recommendation system so noters can get a layout suggestion before sketchnoting. By entering basic information about the content they will sketch, the system will generate a couple of layouts for reference. Sketchnoters can either use the suggestion as the template and build their sketchnote on it or use it for inspiration.

Sketchnote integration tool. This is an alternative solution regarding the layout design. Imagine that noters do not need to decide on the layout before starting sketching. They can draw every part of the contents separately and integrate them afterwards. As noters have already determined the number of contents, the uncertainty of deciding a layout at the beginning of sketchnoting is reduced. Another advantage of this feature is that noters can generate different styles of sketchnoting by simply rearranging the contents of sketchnotes.

7.3 Assist in sketching complex illustrations

Sketch components that can be customised. In the interviews, we asked about participants' opinions of having templates of, for example, icons, symbols or illustrations to accelerate the sketchnoting process. *"It's okay to have it, but I don't think I will use it. It might take me longer to find the one I want. I can just draw it."* (P1) *"I don't think the template would be very useful. Sketchnoting is a very dynamic process. For me, every time is different" (*P2) *" but it might be great to have some commonly used element but take longer to draw."* Participant 2 added. (P2) The feedback is highly matched to our corpus analysis result, in which we found that science sketchnotes use fewer icons and symbols than general sketchnoting. (27 in science sketchnote and 97 in general sketchnote) Considering our result, it could be a set of commonly used components that sketchnoters can revise when using it or have a collection of symbols with different styles but under the same concept.

Practising program that teaches how to sketch. Even though sketchnoting does not require high drawing ability, it does require a certain level of visualising skill, especially in science that involves professional and specific content. Even experienced sketchnoters in our study would encounter difficulties while sketching scientific materials. (Section 6.4) *"it happens, not knowing how to draw."* (P1) Science sketchnoting tools can provide a learning and practising feature that enables users to shadow sketches and build their sketch library. Participants also suggested providing sample sketchnote from common concepts for novices to draw upon their sketchnote on it.

7.4 Educational Purpose

Save different versions of the same sketchnotes for different purposes. In school or educational settings, sketchnotes are used for reviewing learning contents or as teaching materials. One of our participants mentioned how she had used sketchnote to review for exams since she was a middle school student. *"I used sketchnoting to take notes during the class, after the class and before the exam, it is very useful for me because I am a visual learner."* (P1). Imaging that if keywords in the sketchnote can be removed for readers to recall the knowledge or for teachers to create a worksheet for students. With the flexibility of digital tools, this feature can add the value of a sketchnote as it can be used for different purposes.

Video demonstration. Providing video demonstrations for users who are new to trying sketchnoting might be an approachable way for new sketchnoters to accumulate skillsets.

Science sketchnote gallery. Building a shareable platform where both experienced and novice sketchnoters can share their sketchnotes after finishing them and learn from others by appreciating their works.

8. DISCUSSION

Sketchnoting, as we defined at the beginning of this paper: "Analogue or digital science notes that are created from a mix of handwriting texts and visual representations." does not have a strict definition but has the flexibility of including many of these kinds of notes. This paper proposes a series of digital tools and design solutions for assisting science sketchnoting. In previous studies [6,27,33,36], researchers have also worked on investigating digital tools that assist digital note-taking. A question worth considering emerges during the research process is whether we should design one solution for all kinds of digital note-taking or design more specific, specialised tools for subcategories of sketchnoting, such as science sketchnotes. There are pros and cons for both. A tool that can meet the needs of more categories of

sketchnote is fascinating for sketchnoters who would want to sketchnote digitally and give sketchnoters choices and freedom in the creative practice of putting thoughts and ideas into rich visual displays.[36] These kinds of implications sparked the thought for the innovations of digital note-taking tools. In this paper, we have decoded the unique characteristic of science sketchnotes components and strategies, and the design suggestions are specifically informed by the science sketchnotes. These proposals are valuable as we tailored the design to solve the challenges better that sketchnoters might face while sketchnoting science materials and apply sketchnoting skills in educational settings. From our research, we have found that some challenges are specifically for science, such as using mathematical greek and symbols for the equations and scientific meanings and the requirements for accuracy in illustrations. In this case, more specialised tools might be a better fit for sketchnoters with special needs.

In this study, we recruited experienced and even professional science sketchnoters to understand their strategies with years of practice in science sketchnoting. We gained a lot of valuable insights from them, and these data helped us to draw a thorough understanding of the process of creating science sketchnotes and were able to derive design applications from our research outcomes. With the goal of understanding science sketchnoting strategies, we did not recruit novice science sketchnoters as participants this time as we assumed that they might not yet develop their strategies and are still in the learning phase. Therefore, our suggestions for digital design might be specifically for experienced sketchnoters and might lack understanding of novice sketchnoters' challenges. Another point that could be further considered is the thematic coding process. Science is a broad field that includes many subjects and professional areas. It would be a reasonable adjustment if the sketchnotes could be grouped by subjects before starting the analysis. The components of science sketchnotes might have richer and denser results that reflect the difference between different science subjects.

9. CONCLUSION AND FUTURE WORK

This study aims to unpack the design space of sketchnotes and to inform the design of digital tools that can support sketchnoting activities and apply them to educational settings. The first part of this study compared the components in science sketchnotes and general sketchnote. We found that these two kinds of sketchnotes share a few similar features, such as the use of font style to differentiate hierarchy and group written content. Besides some of the similarities between them, science sketchnotes have many unique characteristics other than general sketchnoting. For example, illustrations play a critical role in science sketchnoting that almost exists in every sketchnotes. Five categories of illustrations are found: illustrations for an abstract concept, illustrations for structure, magnify, illustrations for mechanism, and text visualisation. We also discussed the strategies for sketching illustrations used by experienced science sketchnoters. Science diagrams or illustrations are unfamiliar to the public audience and even to the sketchnoters. Therefore, sketchnoters will seek help from other resources, such as the internet and evolve their sketches from other's images. Science sketchnotes cover many abstract and complex ideas that require a deeper understanding of the selected topic for sketchnoters to do the sketchnotes. Many strategies were discussed in this paper to get insights for designing digital sketchnoting tools for science and education. The finding informs our suggestions for design of sketchnote corpus analysis. The suggestions point toward assisting sketchnoters in coping with the challenge they face when dealing with unfamiliar concepts. This research deconstructed the elements of science sketchnotes and provided closer perspectives for sketchnoting activities. The discussion of design implications shows the potential of future digital sketchnoting tools that support sketchnote skillset development.

For the next step of this research, one promising direction is to include novice sketchnoters for a more comprehensive insight into design. Another direction for future research is to investigate the application of our suggested implications for design. The possible focus of future studies can also be how science sketchnotes strategies we found to be applied to educational situations such as school, science classroom, etc. Quoted from one of our participants, *"In my experience visiting schools, science sketchnotes for upper primary and high school students is also a great additional learning tool to allow visual lea to draw out how they think and see science concepts and label processes and biological cycles etc. This also gives the teacher the opportunity to see how the students are thinking and laying out information, exams and questions."* (P3) Sketchnotes in science and education is a fascinating area for research, and designing digital tools that assist the development of this ability is valuable for both education and the HCI field.

ACKNOWLEDGMENTS

We thank all sketchnoters that gave us permission to use their sketchnotes as example illustration in this article. We also thank our interview participants for their insightful comments. Thanks to Professor Nicholai Marquardt for supervising me with this research.

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