Experience and Guidance for the use of Sketching and low-fidelity Visualisation-design in teaching

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ABSTRACT

We, like other educators, are keen to develop the next generation of visualisation designers. The use of sketching and low-fidelity designs are becoming popular methods to help developers and students consider many alternative ideas and plan what they should build. But especially within an education setting, there are often many issues that challenge students as they create low-fidelity prototypes. Students can be unwilling to contemplate alternatives, reluctant to use pens and paper, or sketch on paper, and inclined to code the first idea in their mind. In this paper we discuss these issues, and investigate strategies to help increase the breadth of low-fidelity designs, especially for developing data-visualisation tools. We draw together experiences and advice of how we have used the Five Design-Sheets method over eight years, for different assessment styles and across two institutions. This paper would be useful for anyone who wishes to use sketching in their teaching, or to improve their own experiences.

Keywords: Sketching visualisation designs, Five Design-Sheet, Information Visualisation, Teaching visualisation, Learning Support

Index Terms: H.5.2 [Interfaces and Presentation]: User Interfaces—Graphical User interfaces (GUI). K.3.2 [Computing Milieux]: Computers & Education—Computer Science Education

1 INTRODUCTION

As educators ourselves our vision is to help develop the next generation of visualisation designers. We wish to develop better methods and structures to help students and educators learn creative skills. Indeed, this is why we developed the Five Design-Sheet methodology (FdS) [27–29] and the Explanatory Visualisation Framework (EVF) [30, 33]. The FdS and EVF methods help students and developers structure their work and create better designs and plans. We are not alone in these thoughts. The voices of educators calling for "more design in computing" are getting louder. Robinson writes "*the world is changing faster than ever in our history . . . We need to create environments – in our schools, in our workplaces, and in our public offices – where every person is inspired to grow creatively*" [34]. Educators need to develop skills in students, such that they will have the right skills to tackle unknown and challenging questions in their place of work. In fact visualisation techniques are being used in a wide variety of work places, therefore it is even more important to develop such skills for a broad range of students.

When students are asked to sketch and build low-fidelity prototypes, sometimes they face challenges. In this paper we explore these issues, and ask how to integrate low-fidelity and sketching techniques in education, towards developing the next generation of visualisation and creative computing students. We, not only discuss where problems and issues lie, but offer guidelines and potential solutions.

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2 BACKGROUND & RELATED WORK

In our teaching, we have been focusing on sketching designs. We draw our experiences from teaching and using the FdS for over eight years both at Bangor and Lincoln Universities, and applying the EVF for two years. We acknowledge that there are other models that a student could follow, including the waterfall model which defines requirements, design, implementation, verification, maintenance, or models by Simon [37], Design Council [7], instructional models such as ADDIE [4], Jonassen [15], to Munzner's nested model for visualisation design [21], McKenna et al. [20] (understand, ideate, make, deploy) and the nine-stage design-study model by Sedlmair et al. [35]. In addition, methods such as VisitCards [13] could be used to explore the design space with users, and token and constructive-based tasks using physical objects [14] are useful for concept investigation. We also acknowledge that there is a huge quantity of related work, in other fields, which discusses knowledge that can be transferred to the computing domain; these include Nelson and Stolterman [22] who discuss design competence, the Design Council which provides lessons learnt from design in global companies [7]), architectural design (e.g., Suwa and Tversky [38] and Frederick [12]), sketching and design (e.g., Buxton [5] and Roberts et al. [29]), and prototype building (e.g., Lim et al. [17]).

We have two broad requirements, first to get students to explore the solution domain and initiate new design solutions, and second to create an artefact that they can use as a plan, to help them program an appropriate solution. These two requirements are important because they direct the methods and techniques that we use (namely sketching using the FdS methodology). These creative artefacts are used in a *problem-solving* capacity. In fact, through investigating alternatives the students *evaluate*, *synthesise* and *analyse* the problem domain. These requirements fit into a broader set of learning outcomes. Through our creative tasks, we want to develop a breadth of skills, but particularly students should be able to: (1) *analyse* the problem domain, and create many alternative solutions (2) develop their *knowledge*, (3) be able to *synthesise* many ideas into a few specific solutions, (4) *evaluate* and consider which alternative solutions would be appropriate, and (5) *reflect* on the appropriateness of specific results and their whole experience. Through these learning outcomes, we are addressing the higher level skill-set of Blooms' taxonomy [16].

Exploring the domain through sketching enables the student to examine many solutions, explore the suitability of each, and discover solutions that they originally had not imagined. The sketches help the student to consider many solutions quickly, on paper, rather than building them in code (that would take much time and effort). Indeed, the artefacts provide a plan, that confirms the ideas in the students' mind, such that they have a clear recipe to follow. From a teachers' point of view, the sketches act as a record of the thought process. This is similar to studying mathematics, where a teacher may say "write down the intermediate steps". Grades can be awarded to different sketches, which may demonstrate that the student has considered potential alternative ideas, carried-out research on related concepts, considered usability and design best-practice, etc. The artefacts also allow the teacher to give formative feedback on intermediate sketches and plans, such to keep the student on the right learning path.

Curriculum environment

Learning objectives, curriculum design, modules, goals, reason, options, regulations, laws, timetables, assignment wording.

Physical environment

Infrastructure, building, facilities, computers, pens/paper

Student approach

Student attitude, knowledge, goals, buy-in.

Academic approach

Goals, aspiration, keenness, ability, attitude, support staff

Figure 1: Many actors positively or negatively affect the student experience making them more or less likely to engage with the process of sketching or creating low-fidelity designs.

3 Aspects that affect the learning environment

We define a *learning environment* to be "the context where someone learns". It includes many aspects, from the person (student), physical location, resources given to the learner, perception of the learning atmosphere and the materials that are being taught (the curriculum). The learning style that we are using is active learning [2]. In fact, we would suggest that this is the most useful style to teach visualisation and creative subjects. Active learning involves the learner in all aspects of the learning process. They read, write, engage themselves in solving problems and discuss their results with others.

There are many potential challenges and problems that could arise due to any part of the *learning environment*. Ramsden [25] talks about the dimensions of the learning environment, from commitment to teaching and relationships with students, workload, and formal teaching methods. Ramsden and Entwistle [11] explain that learning can be affected by *approach*, *process* and *outcome*, while Biggs [2] proposes ways to evaluate whether students are *deep* or *surface* learners. However, in regard to deep and surface learners, Choy et al. [6] caution that students are not necessarily able to judge whether they are deep learners, and that the assessment itself can affect how deep the students learn. This has relevance, because we wish to develop deep learners, who are self-motivated, have a broad inter-related understanding of the field and can apply their knowledge to many different situations. It also supports that there are many factors involved in developing an appropriate learning environment, including the assessments.

Learning to sketch better, and getting students to follow design methodologies (e.g., FdS) leads to specific challenges for the student and educator. In addition, the taught material can also have a substantial affect to the learning environment, as well as the physical learning environment. In this short paper we focus on four main aspects (see Fig. 1), briefly explaining potential challenges and discussing our experience: a) the **curriculum** and specifically the task the students are given, which can help to engender creativity or can inhibit creative thought, b) the **physical** settings in which students learn, ranging from classrooms and labs, to reading rooms and spaces to collaborate with their peers, d) the students' attitude and the whole **student approach** to learning, which impinges on how they learn creative skills, and finally, e) the attitude, enthusiasm, knowledge and experience of the **academic** or teacher which affects the students' learning.

4 Curriculum environment – the task

In an education setting we can consider many different assignments tasks. Some tasks are precisely defined, where the results by all students will look similar, such as build a clock or a calculator. These are *well-defined* problems that converge to a single answer. There is a clear solution path, and the student knows in advance what their solution will look like. However, we are more interested with *ill-defined* problems [31], where it is less clear how to build the solution, and in fact, many solutions could be equally valid. For example, students given a task to "design a visualisation" is ill-defined, where there is no clear answer, and the teacher cannot show the student (in advance) what the answer would look like. This type of assessment is exactly what is required to encourage students to make new designs, consider alternative solutions, and to develop their own creative and critical thinking skills. But the task, and even the phraseology of the task, can affect positively or negatively how students develop creative skills. The task needs to be open-ended to engender creativity and allow each student to create their own solution. One challenge is that when students create different outcomes it can be difficult to grade consistently. This can be time-consuming, and may add more burden to the teacher.

The tasks set for the students have to be open-ended, such that students perform *divergent* and *lateral thinking* [8] to create alternative ideas, make judgements over these ideas to create a new data-visualisation. There are no easy solutions to each of these challenges; the teacher must manage this situation to the best of their ability. But while these are *ill-defined problems*, with no single answer, the assessment should still express a specific goal [9], where the student will know that their result fulfils (or doesn't) the problem description. One task we have used is to get students to "choose their own dataset and create a new data-visualisation technique to display their data". Grading this task can occur in thresholds. For example, at the very least students must load and display the data, whereas at the next level they must make their tool interactive, etc. Especially with the latter task the student will need to work out what is important in the data, what aspects may be interesting and how to map the data to specific retinal variables. While appropriate grading thresholds can be used, it is still challenging to grade how they have exercised creative thought, planning and sketched alternative designs, etc. Our solution is to break this big challenge into separate tasks that can be individually graded. We use this strategy for the EVF. We task students to "develop and explanatory visualisation of an algorithm", see [30, 33] and use three separate stages: (i) the students perform research, (ii) students consider alternative designs through sketching with the FdS, which are graded, (iii) students implement their solution and reflect on what they have achieved.

5 Physical environment

The physical environment is recognised as a significant factor for knowledge creation and learning [23, 24, 36]. In our context this physical environment includes: a) the teaching space, whether used for seminars, lectures or lab work, b) the tools available for externalising the ideas, e.g., pens, paper, post-its etc., and c) the means to realise them, e.g., computers, software etc. All these components contribute to an infrastructure that is there to foster creativity and ultimately lead to ideas with impact:

The place. Oksanen and Ståhle [24] discuss the attributes of place (i.e., space with context) that promotes creativity: collaboration enabling, modifiability, smartness, attractiveness and value collecting. In our experience, the place where the teaching and learning activities takes place needs to be an open space, that promotes collaboration and immediacy. Learners should be free to collaborate, discuss their designs with their peers, feel free to take a walk about and relax. When students follow the same task (e.g., through a convergent task), they risk plagiarising ideas from each other. We get all students to have an individual creative challenge (which can be achieved by allowing each student to visualise a different dataset). This releases the students from a burden and worry of plagiarising. This approach is on par with Lippman's [18] recommendation on responsive design of learning environments, where rather than assuming a place is ideally designed for learning, its advantages and constrains inform the learning process. With sketching tasks (such as using the FdS) students need desk space to use pen and paper. Usually, the sessions are scheduled in a computing laboratory, setup for students to use computers, and not to sketch. Indeed, once sat, students will automatically login to the computers. We give the students time to settle and check their email, and get them to move the keyboard to create enough desk space to sketch. The Internet may be used to help engender inspiration. This also fits with the aspect of modifiability of the environment, as described by Oksanen and Ståhle [24], where users can make better use of their learning space by embracing its shortcomings. The smartness and attractiveness [24] of sketching can be improved by seeing previous work. We opt to display previous work, such as visualisations and applications, as posters and banners. Our intent is to inspire and guide, as well as to demonstrate that contributions are valued and celebrated.

The materials: By materials we define non-software physical items that can be used to prototype and realise visualisations. As the FdS methodology is integral to our teaching, we use a collection of materials suitable for sketching. These include: (a) large sheets of paper (A3/ISO216 or Ledger/Tabloid ANSI/ASME Y14.1), rather than sketch-books which can be restrictive, (b) pens (felt tips, alcohol/water based pens etc.) instead of pencils. We prefer pens as they force designers to commit their ideas, instead of spending time adjusting a limited number of designs. The quality of these materials is also important. Much like an artist uses the best oil paints, or a scale modeller the best airbrushes and pigments, a visualisation designer needs good quality pens. We encourage students to purchase their own pack of black water-resistant fine-tipped drawing pens and good quality colour pencils. To balance cost and quantity for the tutorial sessions, we provide students with fine felt-tipped markers purchased in bulk. Quality materials do contribute to the enjoyment and attractiveness of the outcomes, but students (and institutions) need to balance availability and cost.

The technology: An important aspect of the environment is the technology available to learners, both for creating their prototypes, and to realise their final implementations. Even though we are encouraging students to sketch on paper, it is essential for a learning environments to provide access to the Internet, libraries and e-books, which are used as sources of inspiration. Students need software to code the visualisations, and often have to work with pre-selected software that has been installed by University's IT services. For visualisation, the number of open-source, web-based libraries and tools allows great flexibility, while providing contemporary and cutting-edge tools for implementing visualisations.

Nonetheless, our perception of space and place is constantly changing due to technological advancements [26]. We have stopped associating activities with a particular space (e.g., checking our emails on our workstation at home), as we have constant and ubiquitous access to resources, such as cloud stored files, email etc. We now collaborate in shared virtual spaces, whether these are part of an institutions teaching provision such as virtual learning environments (VLEs), or through social media (e.g., Facebook groups, Slack etc.) In the future we may be teaching and learning in immersive environments [32], designing prototypes with tools that evolved from contemporary applications such as Google's Tilt brush. However, despite this shift in our perception of physical space, we expect the basic principles of spaces that foster learning, creativity and innovation will not change, as these are human-centered and socio-technical [1].

6 STUDENT APPROACH

Encouraging students to sketch and prototype in a creative fashion can be a challenge. For some students, drawing is simply not part of their leaned skill-set, and they find its use daunting. This is especially overwhelming for perfectionist students, who may see their own artistic ability as poor and possibly a personal failing.

Knowledge. When young children learn to communicate, they regularly do so through creative outlets. Often a child will paint, and crudely illustrate before they are able to write. However, this natural tendency is often less encouraged by educators, in favour of written or verbal communication. Perhaps the world would be a different place if we evaluated education by sketching and drawing, rather than using writing. In the British education system, students are expected to specialise their learning at 14 when they choose their GCSE examination subjects. This is further narrowed down during their A levels (typically between 16 and 18 years old), followed by a single subject for their degree. Similar models are practised in a number of countries worldwide. On the other hand, all subjects would have required the student to communicate through writing, with less importance on drawing. When students are expected to sketch and draw (such as drawing geographical processes or chemical symbols) there is little teaching on how their sketches should look, how best constructed, how much detail is required and how to make them more aesthetically pleasing. The emphasis, rather, is that they are visually readable, clear and contain the correct functions. Sketching and design skills are excluded from most subjects. This leaves a number of students without the knowledge, and conceptual tools required visualise in this manner.

In our experience we overcome this issue by delivering basic instruction on sketching, e.g., drawing lines, boxes, shading cubes and cylinders, sketching creative alternatives. Some students also find non-permanent mediums (such as dry-wipe surfaces) useful to build their creative confidence. However, while this may be useful in developmental exercises, we generally advise permanence when considering drawing mediums (which will be discussed in the following section). Finally, we refer the students to books which cover basic sketching techniques, such as those from Roberts et al. [29], Buxton [5] and Edwards [10].

Experience. Using sketching as a tool requires some practice. Students may be intimidated by the idea of sketching for planning. It is important to ensure that students understand, that when sketching in this manner it is more important to communicate the idea than focusing on the art. This is an issue we have faced a number of times, students can be more personally concerned with artistic realism of their drawing that they forget the purpose of the activity. We have seen a number of students erase or discard perfectly good concepts for fear that they did not meet a certain graphical standard. Students also need to learn that if they do make a mistake, they should incorporate that error in their design. If it is something absolutely wrong, then to use a simple line to cross-out the design. Students also learn through experience how to place the graphical marks on the page – they need to first imagine (envision) how the end result will look, and where sketches could go on the page.

One method we have used to modify this behaviour is the use of permanent mediums. For example, instead of providing individual pieces of paper, the students could be provided with non-perforated notebooks (where pages cannot be neatly removed). Instead of pencils that can be erased, the students should use felt-tip pens. When students are working in this way we have noticed that they tend to take a little more time considering what they are about to commit to paper. They also quickly get used to the idea that once something has been drawn it is permanently recorded. As such, artistic quality is less of a reason to discard an idea, and if a student moves on, it is to draw something else. Ultimately, the best way to encourage students to sketch is through the facilitation of fun activities that allow them to develop their sketching skills. Sketching confidence/visual communication exercises can also be useful. For example, picture charades-inspired games (e.g., Pictionary) encourage students to visualise a concept quickly in front of peers.

Attitude. "Why do I have to draw?" this quote is not from any one specific student, but an amalgamation of student comments over the years. It expresses an attitude of annoyance at having sketching imposed upon a computer science major student. The "I came here to code" position is sadly not uncommon. Even those on the data-visualisation course want to jump straight into coding. The reality is that the perception of what a student *thinks* they should be learning is not always reflected in what they *need* to be learning. This is not a problem faced only for sketching, but also for maths, business or management skills and ethics. Students need to buy-in to the activity. Some students simply do not value sketching as a skill relevant to their chosen industry. Students that buy-into the concept, are enthusiastic, and engage with the application will always gain more from the experience. So, how do you motivate students to commit to the topic?

Overcoming a negative attitude is difficult, as the student may simply have no interest in sketching or design and could ignore any proposed argument or benefit. One way we have tackled this issue is by highlighting the need for visual representation of certain concepts, by taking a student-centric approach. In one lesson we asked the students (in groups) to write and describe the design of an interface in a way that another student could interpret and potentially implement it. The purpose of the exercise is highlight the limitation of written communication for visual mediums. Within five minutes we had a number of students asking if they could use diagrams within their description to explain some of their ideas. After attempting the exercise for 15 minutes the students were engaged in debate about the challenges they faced, and what the solutions could be. The students unanimously chose to sketch, and we had little negative comments onward: they had naturally concluded that sketching was beneficial through their own experience. In addition, providing an industrial contextualisation has a significant impact on buy-in. Relating the students learnt skills back to activities that they will be undertaking in their career makes the experience more real and relevant. This can also be supported by invited talks from employers. It is worth noting that attitude may also simply be a symptom of poor knowledge and limited experience (as discussed in the previous two items).

Fear of failure. Sometimes students do not know where to start, or how to get a good grade in their assessment. They have a "fear of failure" and as such do nothing or very little, or distract themselves with other tasks, and so hinder their own education [19]. Especially for creative assignments they may not know or realise how to get a good mark; for other assignments they perhaps have relied on memory to regurgitate facts rather than learning the content deeply [11]. These students have a legitimate concern, because creative assessments are graded on breadth, diversity and type of ideas rather than reiterating standard ideas. Indeed, there may not be any "standard ideas" that have been previously created, that could be copied!

Students should be allowed to fail and encouraged to recover. This is important in the creative field of visualisation as students learn creative tasks through experience. They need to actively take part in activities and try out techniques such to hone their skills. We have employed two principal solutions: (1) we provide ongoing (weekly) *formative feedback* (i.e., oral feedback from the instructor that is timely, positive and explains how they can improve their work), and (2) to allow students to *re-submit*. Students can resubmit many times, but each time they submit they lose 10% of that grade. Their final grade is calculated to be the highest grade. This improves the grades of fearful or failing students, yet reduces the quantity of resubmissions because it is not beneficial to students who are achieving 60% or more.

7 Academic approach

Challenges of creative design in visualisation are influenced also by the academic, teacher or tutor delivering the material. We focus on attitude, understanding, and time and effort.

Educator's Attitude. It can be very easy for an educator to come across as negative about a course: an attitude either explicitly or implicitly saying: "this will not be useful, but you have to do it" will not encourage the students to sketch alternative designs and explore different visualisation ideas. Perhaps all academics teaching visualisation classes are keen and enthusiastic; or maybe teachers have inherited classes designed by predecessors.

Even if visualisation is your research topic, it is not always easy to be always positive about it; teachers get tired, and can be under immense time pressure. Educators must make the effort to be well prepared for their sessions, talk with their students and be honest when they feel they are tired and under-performing. Even asking the help of the students can have a very positive effect in the latter's learning experience.

Understand your students. Educators need to be sensitive to diversity, they should acknowledge that students are all different, come from various backgrounds, have varying experience and different motivations. Students learn through different methods; some students quickly realise what is required, whereas others struggle with simple concepts; some take a holistic approach, whereas others favour a step-by-step approach. Ideally we want students to have a good experience, and to be located within a good learning environment; that they know what they need to do, have the skills to do it, discover any missing knowledge on their own, know how to apply it to their situation, and provide a successful result.

To overcome issues in our visualisation modules we have tried to see the world through their eyes. It is not always easy to do so, as educators get older and become more distant from their own formal education. But reflection and empathy with the students can help. Trying to understand what students know, we ask them questions about their prior knowledge. We also wish to understand the students' native creative ability, therefore we ask them to draw something; this gives us an idea of their creative and visual literacy, and indicates who may struggle with the creative tasks. Visual literacy is an important aspect to data-visualisation design, and evaluating the students for it may help you understand the students better [3]. We also discover what pressures they are under (e.g., other assessment deadlines). We give a lecture explaining what we expect the students to do and what skills they will be learning – explaining the Blooms taxonomy [16] helps because it provides a learning model of the different skills they need to develop.

Time and effort. It is important to give ongoing feedback to students as they develop their sketches and creative visualisations, but this takes time and effort. Even giving the students five minutes each, only allows 12 students to be met per hour. Using a well trained Teaching Assistant does help, but ideally we need to train the students be able to self and peer reflect. We encourage students to discuss and critique their work, with their peers. By giving each a different task (e.g., a different dataset to visualise), as aforementioned, they can readily share, discuss and evaluate their ideas and techniques without problems of plagiarism.

8 Conclusion

Creative skills are important in data-visualisation, and sketching skills have an important place in computer science education. We acknowledge that honing creative skills is only one aspect towards developing the next generation of data-visualisation designers and developers. In addition, students need to develop coding skills, understand perception, know how to develop GUI interfaces, and how to manage client interaction and project management. Sketching and creative thinking, however are skills that have been largely ignored in computing education. In this paper we have started to address some of the challenges and we provide pragmatic answers to integrating sketching and creative thinking for visualisation in the computer science curriculum.

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