Refining Rules Learning Using Evolutionary PD

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Abstract. Using glyphs to associate digital media with physical materials has great potential to enhance learning. A key challenge, however, lies in enabling children to author their own glyphs that integrate well with their drawings. One possible solution lies in the d-touch system which uses a topological approach to structuring glyphs. Through a series of Participatory Design studies, we have explored how children can be supported in creating their own d-touch glyphs. Main highlights from our findings indicate that it is difficult for children to create glyphs following only written rules. A structured diagrammatic approach is then introduced in which colour-coded hierarchy diagrams support a mapping between their drawings and the underlying rules. We found this has significantly improved their drawing attempts. The paper then concludes with a potential to integrate the approach into more sophisticated learning experience.

Keywords: Drawing rules, visual diagrams, d-touch glyphs.

1 Introduction

Glyphs have emerged as a powerful and popular way of embedding digital media into physical materials. Current glyphs however are predesigned and do not always fit well aesthetically in terms of the content they project, the loci of their placement, or human preferences. This is because current systems operate on geometrical feature detection to localise the barcode placement and encode their unique identifiers. The challenge for us then is to enable children to author the glyphs for themselves in the same way that they can already draw pictures on a page.

Fortunately help is at hand due to a new approach to authoring personalised glyphs that is embodied in the d-touch system [1]. We feel that d-touch opens up an important opportunity for personalised glyphs to be used by children for learning in the classroom. However, while this technology is exciting, it also creates new issues, such as facilitating proper glyph making process. To do so, the needs of child users must be considered as they perceive differently and has different considerations and requirements from other user groups [2].

Our paper therefore reports an iterative exploration of working with children in schools to explore how they can be supported in authoring d-touch glyphs. We begin with an initial study of whether children can follow written rules for generating glyphs. The results of the study suggest that additional support is needed, leading us

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to introduce a more structured approach involving visual diagrams and supporting tools to guide the drawing process. Further studies suggests that children can work with this structured approach and that it has the potential to enable them to author d-touch glyphs that might be used as part of learning experiences.

2 The d-touch Glyph System

d-touch [1] is a glyph recognition system that allows users to create their own bar-codes. The novelty of d-touch lies in its topological recognition algorithm. With d-touch, glyphs can now carry direct visual cues that enable viewers to infer beforehand the information that they may hide.

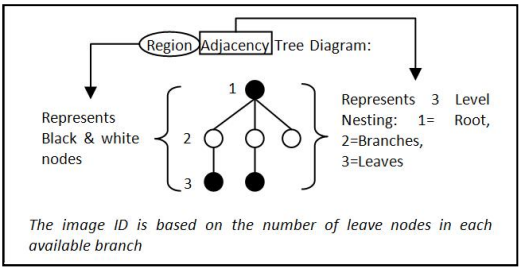


Fig. 1. d-touch Topological Glyph Recognition Algorithm

Glyphs are based on the form of a constrained binary tree as shown in Fig. 1. We say constrained because for a glyph to be valid, its associated tree must satisfy three key constraints: (i) there must be at least three levels of nesting (root, branch and leaf); (ii) there must be at least 3 branches present; and (iii) at least half of the branches must have at least one leaf each. These rules are intended to achieve a balance between flexibility of design and reliability of recognition as explained in [1].

However, it is not clear whether younger children would be able to apply the algorithm – which at first sight appear complex and technical sufficiently well to be able to create their own glyphs. Following this, we revised the drawing rules to assess how well this could facilitate glyph making process.

3 Evolutionary Participatory Design

In order to create valid glyphs, the algorithm properties of these glyphs need to be thoroughly understood. With that motivation, we have conducted several Participatory Design studies which we termed as Evolutionary Participatory Design (EPDs). The EPDs is inspired from the Seeding, Evolutionary Growth, Reseeding (SER) model [3], where results and observation from each study is fed to the consequent PD study by enhancing, restructuring, removing or continuing the task until the design goal is achieved. The process flow can be seen in Fig. 2.

There were four different PD sessions, each with different sets of children. In total we had 29 children (aged 10 to 11 years old) giving feedback to our rules learning process. The age group is selected as it is believed they could understand and follow rules and are able to express drawings well [Sawford, personal communication].

Recruiting different sets of children for each study allows the unbiased identification of design problems as none of the children would be influenced by prior experience.

Each PD set observes the session structure (one to one, group session, workshop), rules briefing (describing and presenting rules), artefacts (hand-outs, glyphs assessment tool) and task activities. Each component has its own distinguished characteristics which were designed to support and feed other components as a holistic rules learning process. These components were scrutinized as separate parts and formalized for the next PD session.

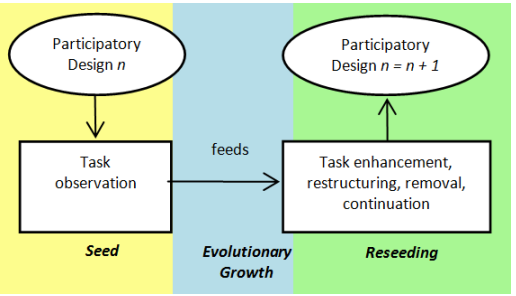


Fig. 2. Process Flow in Evolutionary Participatory Design adapted from [3]

4 Study 1: Following Written Drawing Rules

Study 1 was conducted as one-to-one where a facilitator sits next to a participant and briefs each of them on the study and rules. 7 children participated which lasts 45 minutes average for each session. The children were asked to draw their favourite animal by following our revised d-touch drawing rules. For each attempt, they are required to check the drawing validity using DTAnalyser (a drawing analysis tool that verifies how a drawing fits with the recognition algorithm [1]). A valid glyph is then used to trigger computer content which allows children to see how a glyph functions.

Table 1. Revised Drawing Instructions for Study 1

Previous d-touch Rules	Revised Drawing Instructions
A glyph must have at least and at most 3 levels of nesting – root, branch and leave	Using black marker pen, draw objects which can be considered as animal body parts (head, neck, body, etc). You should at least have 3 objects and all objects drawn must be joined together
A root is assumed as the black region which contains a minimum of 3 white regions	
At least half of the branch or white regions must contain black regions (leaves). The leaves should only connect to the branch and not the root	Using blue marker pen, draw lines or dots inside the black objects as animal features.
	The blue lines/dots should not touch the black object. If it does, overwrite it with black marker pen, or draw a new drawing but make sure the lines/dots appear smaller and no longer touch the black object.
	At least half of the object drawn should have some blue lines or dots inside it. Objects cannot appear inside objects.

4.1 Results and Findings

Table 2 summarises our observation of children's attempts in terms of the number of iterations required to create a valid glyph as well as common errors made, and also shows their final drawing. In general, we observed that children started off by drawing objects then adding lines/dots inside the objects. It was when adding the lines/dots that seemed to create most problems. As the drawing was analysed using DTAnalyser, lines/dots placed too close to the objects could be detected as being part of the objects. Additionally, incomplete pen strokes and gaps in large filled areas also modified the apparent topology. Such effects could easily lead to breaking d-touch rules such as: *"at least half of the objects drawn should have some blue lines or dots inside it"* and *"no objects are allowed inside objects"*. This caused confusion for the children who felt that they had followed the rules well. We also observed confusions over distinguishing objects and lines/dots and also the number of leaf and branch nodes required in an image.

Table 2. Summary of Children Output from Study 1

<table>
<tr><td>P1</td><td>  </td><td>P3</td><td>  </td><td>P5</td><td>  </td></tr>
<tr><td colspan="2">No. of iterations: 3</td><td colspan="2">No. of iterations: 5</td><td colspan="2">No. of iterations: 4</td></tr>
<tr><td colspan="6">Errors made: (i) Lines/dots touching objects, (ii) drew objects inside objects</td></tr>
<tr><td>P2</td><td>  </td><td>P6</td><td>  </td><td>P7</td><td>  </td></tr>
<tr><td colspan="2">No. of iterations: 2</td><td colspan="2">No. of iterations: 7</td><td colspan="2">No. of iterations: 5</td></tr>
<tr><td colspan="6">Error made: Lines/dots touching objects</td></tr>
<tr><td>P4</td><td>  </td><td colspan="4">Error made: Drew objects inside objects
Number of iterations: 4</td></tr>
</table>

In short, it appeared to us that while the children could ultimately draw valid glyphs from the written instructions, that this was a frustrating process requiring multiple iterations while they struggled to comprehend both the rules and using DTAnalyser. We concluded they required greater support of some kind.

5 Study 2: Following Hierarchical Diagram

Study 2 was conducted as a group session where all 6 children sat in a group. A facilitator briefs them on the study and the rules. The study lasts 45 minutes. As we had learnt that children had difficulties in following textual instructions, we explored if rules presented using diagrams might be easier to understand. By doing so, we can

reduce the amount of cognitive effort required in learning [4]. In response, and inspired by the visual form of the d-touch rules in Fig. 1, we developed a form of hierarchical diagram (see Fig. 3) with the following characteristics:

1. Mimic the hierarchical topological structure of a d-touch glyph
2. Support rule inference though labelling in the diagram [5] and using colours

The intention behind using a diagram that mimics d-touch binary tree is to provide a starting point for user to think through the details that need to be present in a drawing so that it can act as a glyph, hopefully helping them bridge the gulf between the topological structure required by d-touch and the visual detail that they, as an author, might want to include. The use of colours (e.g. blue for body parts, red for features) is intended to help with this and also enable easy referencing later on. We did not proceed using black and blue as in previous study as these colours have similar hues making it difficult for children to tell them apart in a glance.

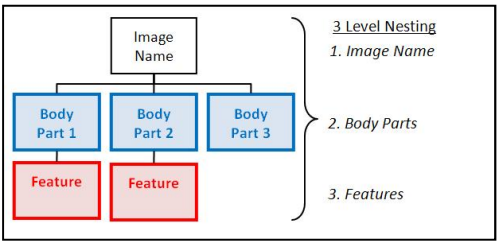


Fig. 3. Basic Hierarchical Diagram

The structures of these rules were presented using two slides; each slide containing hierarchical diagram and corresponding glyph. Children were described how red and blue blocks can be represented with drawings. They were explained that body parts (blue blocks) are represented with blue outline, while features (red blocks) are presented with red filled patterns. No hand-outs were given as it was felt that the slide brief left on the projector screen was good enough as a reference point.

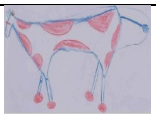
Children were asked to draw a glyph based on a given hierarchical diagram. They were encouraged to ask questions, discuss amongst themselves on how the valid glyph should look like. Due to the limited session time we had with the children, the children were only given two attempts regardless of the final results.

DTAnalyser was problematic in the previous study as it gave confusing feedback to the children which hindered productive learning process. We opted for a manual checking mechanism. This is simply facilitated with the use of colours and correct number of representation by cross-referencing between produced glyph to the given diagram.

5.1 Results and Findings

Table 3 summarises our observation of children's attempts in terms of errors made and also shows their final drawing. In general, we observed that children began by drawing body parts then adding in features. The use of contrasting hues has definitely helped in distinguishing body parts and features. The blocks in the diagram helps to visualize how features are calculated into the algorithm topology however the number of representation required in the glyph was still confusing to some.

Table 3. Output from Study 2

P1		P2		P6	
In terms of numbers, all of the body parts and features were correctly represented. However, the positioning (touches body parts) and patterns of all features were erroneous					
P3		P4		P5	
These three children didn't seem to grasp the concept of block's representation using shapes and patterns. Even the numbers of representation is wrong.					

A general conclusion that can be drawn from the children's drawing was they were keen in producing realistic drawing that did not fit technically to d-touch algorithm.

6 Study 3: Using Orderly Blocks and Templates

This session was conducted as a workshop setting with 8 children. The facilitator briefs them on the study and the rules and the study lasts 30 minutes.

We were able to observe from the previous study that the hierarchical diagram was helpful in visualizing algorithm rules to the children but they needed further support, particularly the form of drawings acceptable to the algorithm. Following this, we introduced the use of templates that suggests acceptable drawing types (See Fig. 4).

Following a suggestion from a teacher, we now called the hierarchical diagram orderly blocks (OB) as it involves putting the entire blocks label into an orderly fashion. Clearer definition were also devised; body parts were defined as *"distinctive parts of the image you can separate into big chunks"*, while features were *"tiny pieces that appear inside the body part"*. We also provided the following drawing guidelines: *"body parts drawn must be joined together"*, *"features must be drawn inside body parts it appears in and should not touch the outline of the body parts"* and *"features must appear in at least half of the body parts drawn"*.

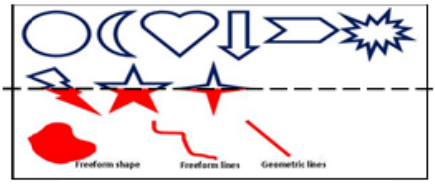


Fig. 4. Partial Template Guide for Body Parts (top) and Features (bottom)

Using Orderly Blocks. Compared to the previous studies, children relied on visual examples on how glyphs are structured. But in this study, we illustrated how OB can be constructed. We began by drawing a cat OB diagram, carefully choosing elements that best represent a cat and organizing them neatly. In addition to the placement of each block in its respective nesting level, the use of blue and red also makes it easy to identify which are body parts and features (see Fig. 5).

Making use of the templates, rules and definitions, a glyph is then produced through visual mapping process. Each of the blocks is represented using proper illustration from the templates, resulting into a glyph shown in Fig. 6. Again, the use of blue and red proves useful as one can easily cross reference between OB and the templates. The corresponding d-touch binary tree is also depicted in Fig. 6. Observing closely, one can see that the number of branch nodes and leaf nodes in the binary tree matches with the OB in Fig. 5. This indicates how we have made d-touch's recognition algorithm visible through OB.

Note as well, how the OB has a block labelled *'head + 2 ears'* (see green circled area in Fig. 5). These are not listed in three separate blocks (e.g. head, ear 1, ear 2) because, in the glyph, they have been drawn using one blue shape outline (see green circled area in Fig. 6). The use of the plus (+) sign implies that one outline represents a combination of two (or more) body parts. However, if the ears were drawn as shown in Fig. 7, then two additional blocks must be added to the OB as the ears are represented with two separate outlines (see green circled area in Fig. 7).

The hand-outs given to the children mimics the presentation briefing where it describes how glyphs can be produced using OB. It makes heavy use of diagrams where text serves as accompaniment to the diagrams.

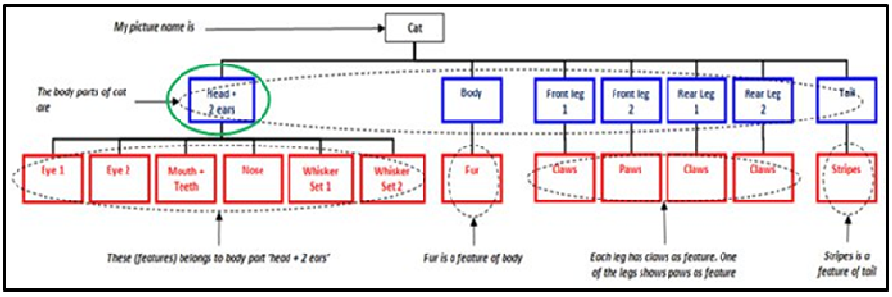


Fig. 5. OB of Image Cat

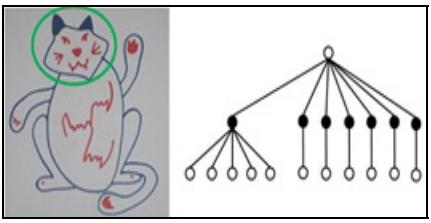


Fig. 6. Cat Glyph with Corresponding d-touch's Binary Tree

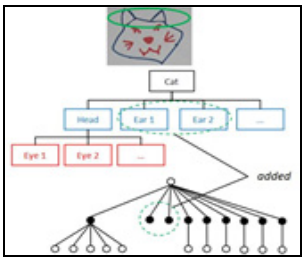


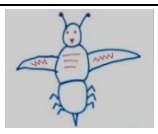
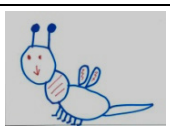
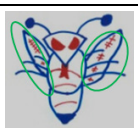
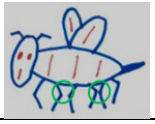
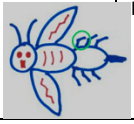
Fig. 7. An Alternative Glyph and Corresponding OB and d-touch's Binary Tree

Children were asked to draw a glyph based on a given OB. Even though children could manually check how their end glyph corresponds to the OB, we have prepared a d-touch glyph reader that plays a gif animation should the resulting drawing match the OB structure. This provides quicker evidence that something is not quite right with their attempt and would allow children to study their glyph and see what needs correcting.

6.1 Results and Findings

Table 4 shows glyphs produced by the children. Glyphs produced by P2 and P5 matches with OB. In contrast, the rest of the glyphs did not. Due to the limitations of d-touch's recognition system[1] embedded in the glyph reader, some drawing strokes and the room's lighting conditions could create drawing noise that unintentionally make additional outlines or patterns appear to be present in the drawing. When this happens, the reader scans the picture as matching the OB structure hence triggering the content. This has caused the children to miss the error made hence not able to learn from their mistakes. The scanning errors are highlighted with green circle and explained accordingly as missed errors.

Table 4. Output from Study 2

P2		P5		P3			
				Missed Errors: Objects more than required			
P1		P4		P6		P7	
Missed Errors: Lines drawn scanned as objects							

[1] An open-source application made available by d-touch author at `www.d-touch.org`

We have also observed that children did not make full use of the hand-outs, only referring to selected pages.

In spite of this, it must be acknowledged that most of the body parts and features were drawn with proper visual representations, indicating a satisfactory visual mapping process by the children.

7 Study 4: Following Revised Orderly Blocks

This session was conducted as a workshop setting where all 8 children sat in a group. The facilitator briefs them on the study and the rules. The study lasts 30 minutes.

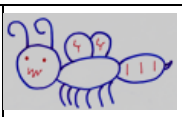
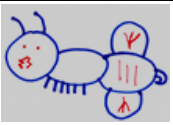
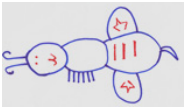
Hand-outs are kept to minimal – only showing examples on cat OB and glyphs as well as templates. This kept their focus on the board and allows referencing to the hand-outs when in need of a clearer view of the rules description.

The same exercise and checking mechanism applied in Study 3 were observed in Study 4. However, we have learnt that children struggled when making representations for block labels with joined body part (i.e. 'head + antennae'). Therefore, children were further trained on this concept further through brainstorming exercises. To minimize recognition error by the d-touch reader, we emphasised the need for each blocks and drawing representation to be clearly and correctly presented. We indicated that computers are bound to errors so they need to design their glyphs clearly.

7.1 Results and Findings

Table 5 shows glyphs produced by the children. All of the children had no difficulty producing valid glyphs that correspond to the given OB within their first attempt. It is believed the brainstorming exercise conducted was useful in getting children to understand the concept of proper drawing representation that conforms with OB structure and labelling.

Table 5. Output from Study 4

P1		P2		P3		P4	
P5		P6		P7			

8 Conclusion

Our studies reveal that authoring interesting and valid d-touch glyphs can be a challenging task for children. This is due to the relatively complex topological rules involved. Our studies also suggest that children may find it easier to understand the topological rule structure through the use of diagrams rather than only written instructions. Thus, the OB with the use of hierarchy, labelling, colours and supporting

templates provide a foundation to bridge between the complex abstract topological rules and a particular concrete drawing.

When learning a new application, it is empirical that children are supported as much as possible. This comes in the form of facilitation, hand-outs, demonstration and checking mechanism. Children should also be trained as much as possible on rules application, particularly in the visual mapping process.

As the PD study progresses with each evolution phase, favourable response can be seen from participants indicating an improved learning structure. With this, we will conduct further studies to observe children author their own glyphs based on a learning theme. This not only further affirms our current observation but also allows the actual authoring itself without relying on pre-given data (i.e. OB). This reflects a further general finding from our studies – that authoring a glyph might best be thought of as a complex and iterative process rather than being a 'one off' process of making a drawing to some rules.

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