Evaluating Children's Engagement with Technology Through the Lens of the Grammar of Visual Design

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ABSTRACT

In this pictorial, we describe a user study carried out with a group of 20 first graders (ages 6-7). The aim of the study was to investigate if it is possible to infer children's engagement with technology by looking at their drawings. The analyses of children's drawings was informed by the Grammar of Visual Design (GVD) and the results evidence that children's drawings provided valuable insights, helping to understand children's engagement and involvement with the tool. Applying the GVD to inform the analytical process reduced subjective interpretations of children's drawings. As such, this work adds evidence to the body of knowledge that seeks to validate more reliable methods to assess children's opinion in user studies.

Author Keywords

Digital Manipulatives; Tangible Interfaces; User Studies; Storytelling; Drawings; Children.

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CSS Concepts

•Human-centered computing~Human computer interaction (HCI)~HCI design and evaluation methods~User studies

INTRODUCTION

The difficulties to evaluate technology with young children are widely acknowledged [1, 3, 8, 9]. Children may have difficulties understanding interview or survey questions, or/and expressing their thoughts, feelings, and opinions trough words [1], also, their responses may be influenced by a desire to please adults [1, 3, 8, 9].

In face of such difficulties there have been various attempts to develop evaluation tools specifically directed to young children that do not ask children to express their opinions through words. Some examples are the This or That Method [25] or the Paper Ladder [20]. The first asks children to point out to one of two interfaces to indicate their preferences, the second uses cut-outs that children can position on a paper ladder to indicate their preferences. Drawings have also been used to study children's understanding of technology [4, 6, 15, 21], and to measure the amount of fun that the children experience by interacting with technology [22, 23, 24]. In [18], the authors used drawings to assess children's perceptions of urban landscapes to inform the design of digital maps. Children's drawings are also used in the Cooperative Inquiry, a design technique that involves young children as design partners [7]. Aiming at gathering evidence to the body of knowledge that seeks to validate methods to assess children's opinion in user studies, we have carried out a user study with a class of 20 first graders (ages 6-7) analysing children's drawings to assess their engagement with a storytelling authoring tool that aims at supporting children's narrative creation. Our research question was as follows: Is it possible to infer children's engagement with technology by looking at their drawings? To answer it, we examined the drawings that the children have created after interacting with the tool in class.

THE ROLE OF DRAWINGS IN CHILDHOOD

The importance of drawing in children's development is well established, having a central role in early education. Drawing is often used to assess children's learning after a particular activity [5]. According to literature it is often easier for children to express their feelings, thoughts, or opinions through drawings then through words [2, 10, 14]. According to [2] *Making drawings gives young children opportunities to represent intricate personal narratives and use them to communicate with significant others in their lives* [2:116].

Drawings provide important knowledge about children's thinking and serve as self-expression that verbal measures may not allow [14]. Drawings can also help children understanding their experiences [2,6,10,14,19]. Children's ability to represent the world around them

graphically develops gradually, and although there is a progression throughout children's drawing development, there are no defined boundaries between the different periods. Lowenfeld and Brittain [12] name the period, when children consciously begin to draw forms that have a relationship to their environment, graphic communication. They identified six development stages: Scribbling (2-4); Preschematic (4-7); Schematic (7-9); Dawning Realism (9-12); Pseudo-Naturalistic, (12-14) and Period of Decision during adolescence.

Here we briefly refer to the Preschematic stage, as it is related to our target group. During this stage, children make their first attempts to represent their environment, consciously creating forms that have a relationship to the world around them, and their drawings reflect how they perceive the world.

Children's representations during this stage do not correspond to the way things look like in reality [13]. Whereas adults seek for realistic representations, for children, realism means that the drawings contain all the elements, even the ones that are not visible. Luquet [13] calls this intellectual realism, in contrast to the adult's visual realism [13]. Intellectual realism results from the internal model that children have of the things. Children do not see the same details as an adult; they see them only to the extent that they interest them [13].

Thus, what children draw has a preponderant weight in their mind [13]. Children also do not draw the details that they find unnecessary or secondary, but they tend to draw all the details, even the invisible ones if they believe that these are essential for the representation of what they are drawing (e.g., the child draws the head underneath the hat) [13]. The importance that children give to the details of a particular object often depends on the importance they attach to their role and their function [13]. The exaggeration of a detail often reflects the importance it has for the child [13].

Based on the role that drawings play for children, we inferred that the drawings that children produced after

Figure 1 – The tool

interacting with the authoring tool provide important information about their engagement with it.

THE TOOL

The storytelling authoring tool aims to encourage young children's narrative competencies by assisting them in the production of narratives. It uses physical blocks to manipulate the digital content and is composed of a series of blocks with each block representing a story element. Connecting the blocks to each other, triggers its digital representation on a device's screen (fig.1, 2). The digital story elements interact with each other on the screen according to a set of interaction rules [17], displaying specific animations and different actions depending on the combination of blocks that are connected to each other. The story environment represents elements from different countries. Each country comprises a landscape, two protagonists, an animal, an antagonist, a musical instrument and a magical object. To customize the stories, there are blocks that represent weather conditions: rain, storm, wind, snow, and night. Children can use these in their stories. The story elements are intended to act as

triggers for children's storytelling, and the visual narratives unfold according to the combination of blocks that the users connect to each other, while they verbalize their stories.

USER STUDY

The study was carried out in a public primary school in Portugal with a class of 20 first graders (6 to 7 years). The intervention was agreed with the teacher and took place twice a week. It comprised eight sessions, each lasting circa two hours.

Procedure

The study was integrated in the regular classes and carried out by the teacher in collaboration with two researchers. The sequence of the tasks was defined by the teacher according to her pedagogical approach. The first session

Figure 2 – Story elements displayed on a devices screen

was dedicated to introducing the tool to the children. In session 2 the children played with it in groups of three. They were curious about the various story elements, and actively explored the interactions between them, trying out different combinations of elements. Session 3 and 4 were dedicated to talk about the story elements. Session 5 and 6 were dedicated to storytelling. The groups began by playing with the tool and then the teacher asked them to tell a story using the tool. In session 7 the groups were asked to write a story with the story elements. In session 8, the children were asked to make a drawing of the activity. With the permission from the children and the teacher the researchers photographed each drawing, collecting a total of 20 registers.

Coding

The drawings were coded by two researchers independently, following a two-step protocol: (1) identifying the elements on each drawing and the types of interactions they depicted (2) performing a visual analysis of the drawings' informed by the Grammar of Visual Design [11]. The inter-rater agreement was 92%. A key dimension of the Grammar of Visual Design is the notion that the meanings are organised in systems of representation [11]. So, in the meaning-making process each system of representation (e.g., appearance of the characters, social distance, power, setting, etc.) has potential meanings.

The researchers performed a mapping of children's drawings guided by the systems of meaning representation and identified those that were present in children's drawings. This step identified the systems that stood out in the construction of the meanings related to the story elements and the interactions that compose the storytelling environment.

Analyses of the systems of meanings

The analysis of the drawings was informed by the Grammar of Visual Design, taking children's perspective, that is, how the drawings transmit children's relationship towards the story elements.

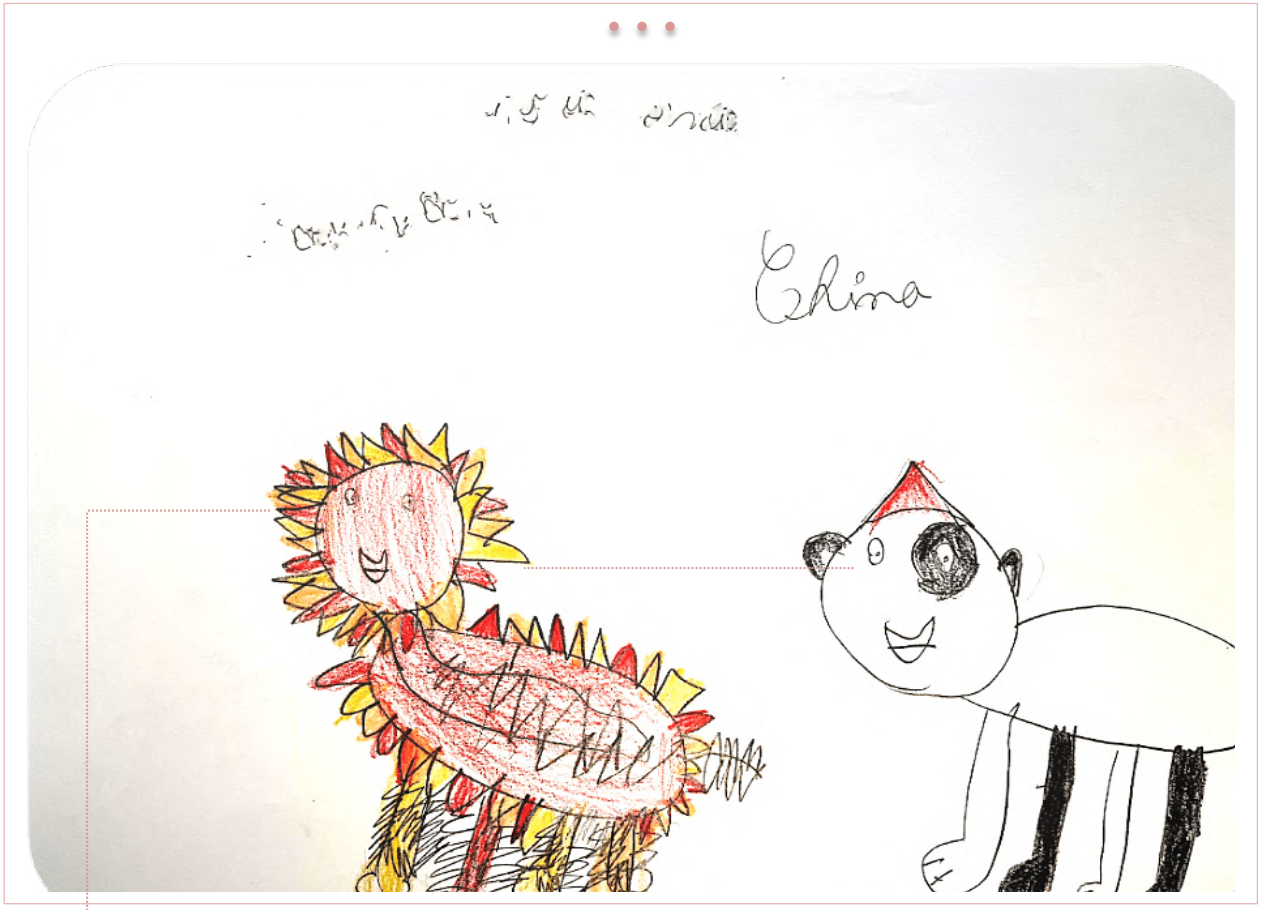

Figure 3 – Visual Contact & Involvement the characters face the viewers

The predominant systems of meanings present in children's drawings were *involvement, visual contact, focus and ambience*. *Involvement* refers to positioning the visual representation in a horizontal angle, that is, the characters are presented facing the viewers 'front on'. This shows an intense relation from the drawing's author with the characters. Characters depicted in an oblique angle (not facing the viewer), show a weaker relation from the author of the drawings with the characters [11, 16]. In 18 drawings the characters were presented facing the viewers showing the involvement of the children with the characters (fig.3).

Visual contact refers to images where a depicted character gazes out at the viewer (as of requesting some kind of participation and engagement). In 18 drawings the

characters gazed out at the viewer. Again, showing the involvement of the children with the characters (fig.3).

Focus refers to the positioning of the depicted elements in each page, which has implications in the understanding of their importance in the depicted scene (the more central, the more important). In 16 of the drawings the animals and the antagonists were depicted in the centre of the drawings. Again, showing the involvement of the children with the characters (fig. 3, 4).

Ambience refers to the use of colour to convey a mood to the viewer: ±vibrant, ±warm, and ± familiar (the more vibrant, warm and familiar, the more excitement and vitality). 15 drawings presented vibrant colours (fig.4).

Regarding the depiction of the interactions between the elements, the systems *kind of action and power* were especially informative, and were depicted in 18 drawings.

Kind of action concerns the characters' actions, realised by vectors (imaginary diagonal lines), (fig.4), while *power* concerns the representation of greater, neutral or less power relations among participants. A visually lower representation indicates less power, an eye-level or higher vertical angle representation indicates more power (for more details, see [11, 16]) (fig.4).

Regarding the *power* relations, in 7 out of the 10 represented conflicts, the antagonist was shown as the most powerful character. This asymmetry is achieved by: (i) the presence of vectorial elements; and (ii) the depiction of the antagonist as the highest one or placed in a higher position (fig. 4).

The *vectorial element,* i.e., the fire line, connects two elements that can be understood as an actor and a goal. The actor is the element from which the vector emanates, and it is the most salient participant of the interaction [11:63]. In these drawings, the antagonists are depicted as

Figure 4 – Example of story elements showing power relations, focus, ambience, and kind of action

actors, thus being the focus of the scene, while the animals are the passive participants (fig.4, 5).

The vertical angle is understood as the realisation of power in the visual semiotic [11], i.e., what is in the upper position has power or authority, while what is in the lower position seems weak or vulnerable.

The *depiction in the foreground* indicates the high importance of these elements to the author of the drawings; and the frontal angle encodes involvement [11:136] (fig. 3, 4, 5, 6).

The centred representation is another indicator of the importance of these elements to the author of the drawings, since when the centre of the space is filled, the viewer's gaze is directed to that element in an unambiguous way (fig. 3, 4, 5, 6).

Greater or lesser involvement with what is depicted is achieved through the horizontal angle, when characters and settings are presented *facing the viewer 'front on',* it suggests a maximum sense of involvement from the author of the drawings with the character, differently from the depiction at an oblique angle [16:17]. The *inclusion of details* suggests the importance that those have for the child [13].

The choice of *vibrant colours* generates a sense of excitement and vitality [16:37], suggesting the involvement with the depicted elements (fig. 3, 4, 5).

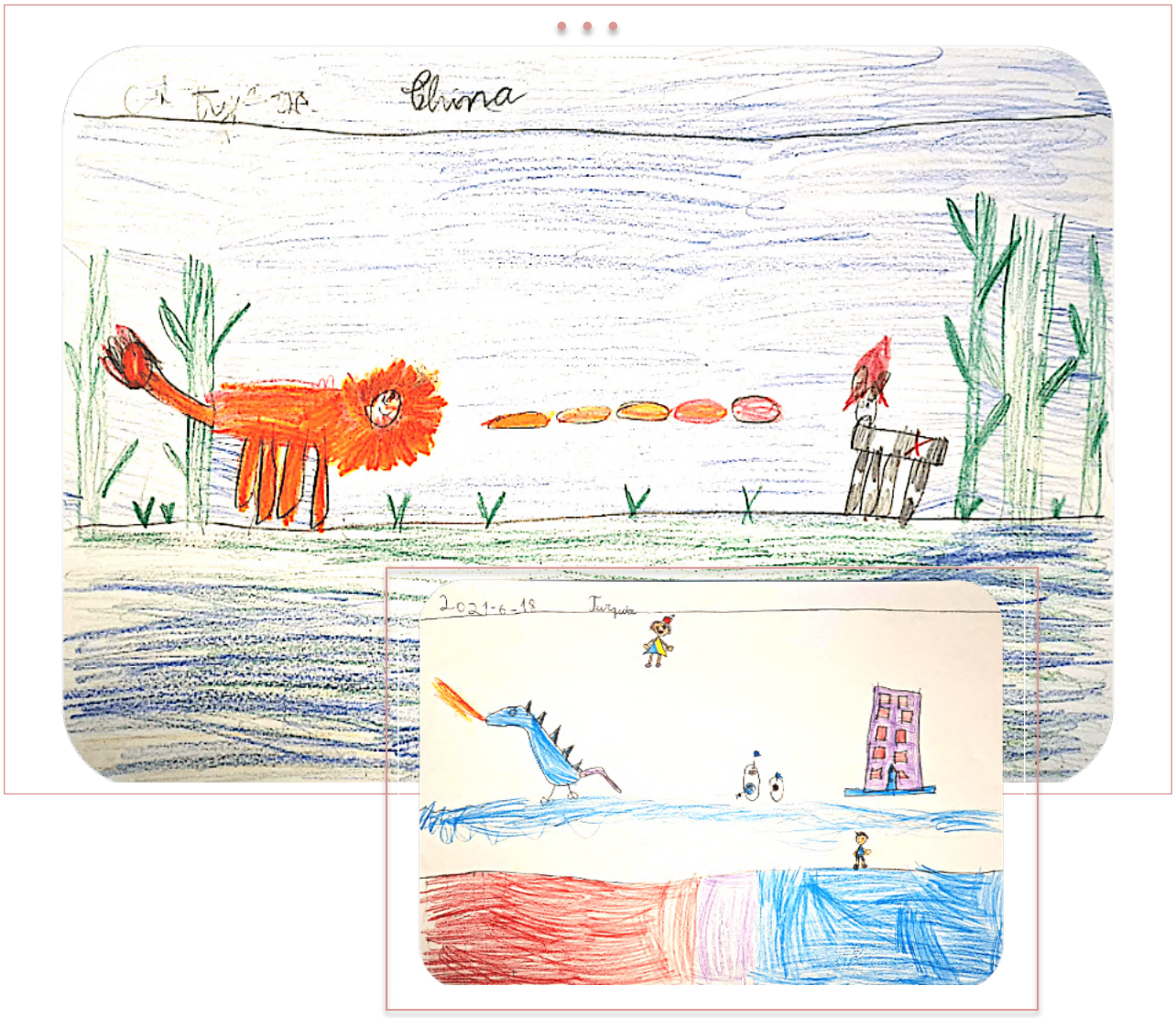

Figure 5 – Example of story elements showing a vectorial element, and a vertical angle.

Inclusion and Detailing of the Background

The inclusion or detailing of the background shows its significance for the children, revealing their relationship with it [16:78].

The fact that 60% of the children included details of the landscapes suggests that they called children's attention (fig. 6).

Figure 6 – Example of central representation, (center) and detailing of the background (left).

The Weather Conditions

The weather conditions were frequently depicted (fig. 7). They usually act as a background element.

The depiction of such conditions can be also understood as a detailing of the background context, which suggests its significance for the child [13, 14, 16].

Figure 7 – Examples of the representation of the weather conditions

Self-Representation

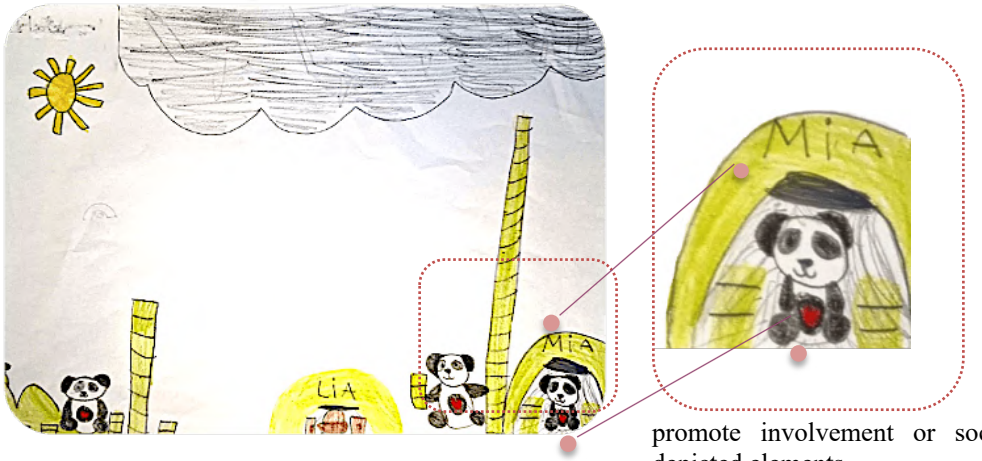

Figure 8 – Example of self-representation

Nine children depicted themselves in their drawing, and explicitly verbalized it. This is an indicator of the level of involvement that the experience raised in them, as children represented themselves as being part of the story [5, 19] (fig. 8).

The children personalised the elements, including more details and/or new features in the elements' depiction. Considering that children only include details that they think are essential and that the number of details included in the depiction of a particular element is often related to the importance children give to it [13], the fact that they have personalised the elements can be interpreted as an indicator that these children have appropriated the elements and were engaged with the experience.

In this drawing (fig. 8), the child personalized the panda, by including a red heart in its representation. This element is not in the original depiction of the panda, and it may represent an emotional involvement. Moreover, the girl drew three pandas, not only one. This repetition is also an indicator of the child's identification with the depicted element. Finally, the child gave names to the pandas (i.e., Lia, Mia), which is a linguistic resource to promote involvement or social proximity with the depicted elements.

Personalization

In this drawing (fig. 9), the Chinese antagonist, is represented with many details. The child drew the dragon's fingers, tooth, and colourful scales. It is likely that this child was inspired by the Fire Dragon legend that has inspired the design of the Chinese antagonist. Regarding the Chinese animal's facial expression, it is possible to identify the angry face of the panda, including the arched eyebrows. As we argued before, the exaggeration of details suggests the importance that these elements have for the child [13].

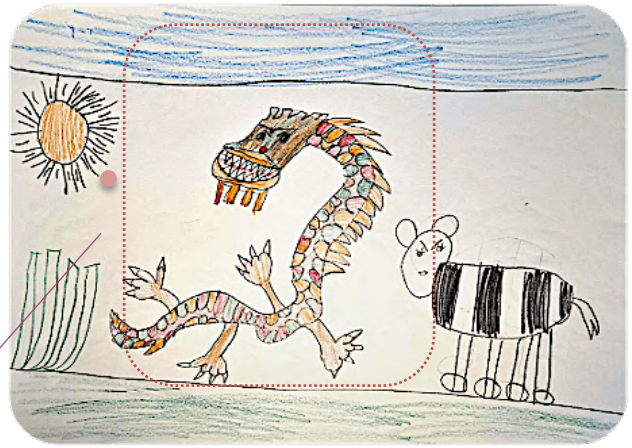

Figure 9 – Example of personalization

CHILDREN'S PREFERENCES

In the children's drawings, the most represented elements were the antagonists (75%) followed by the animals (70%). Their percentage of representation is relevantly higher than the percentage of the other elements, i.e., human-like characters 35%, objects 25% and instruments 10%, suggesting that the antagonists and the animals were the elements that children liked the most. The representation of the antagonists and the animals was followed by a small distance by the landscapes (60%) and the weather (50%) (table 1).

The predominant interactions were the conflicts, between the animals and the antagonists, which were depicted in 50% of the drawings (table 2).
Besides being the most depicted elements, the animals and the antagonists were usually represented: (i) in the foreground with frontal angle; (ii) in the centre of the page; (iii) facing the viewer; (iv) with many details; and (v) in vibrant colours. This shows their relevance to the children.

Table 1 – Story elements

Story elements	Nr. depictions	%drawings
Characters	7	35%
Animals	14	70%
Antagonists	15	75%
Objects	5	25%
Instruments	2	10%
Landscapes	12	60%
Whether	10	50%

Table 2 – Interactions

Interactions	Nr. Depictions	% drawings
Conflicts	10	50%
Music/dance	2	10%
Use of objects	2	10%
Static situation	9	45%

WRITTEN STORIES

Given that as part of the intervention in session 7, as reported in the user study, the children wrote a story in small groups with the story elements present in the storytelling tool, we also looked at the presence of the story elements in the stories. We analysed a total of 6 stories. The animals were present in all the six stories. Four stories included a conflict between the antagonists and the animals. Two of the stories did not present any conflict. Story 1 had 3 conflicts (panda and dragon/ cat and dragon/ dwarf and cat).

Table 3 – Representation of conflicts

Groups	Nr. of animals	Animals & antagonists	Nr. of conflicts	Conflicts
Group 1	4	Panda/Dragon Cat/Dwarf	3	Panda/dragon Cat/dragon Dwarf/cat
Group 2	1	Dragon	0	0
Group 3	3	Panda/Dragon Cat	2	Panda/dragon Cat/dragon
Group 4	2	Squirrel Panda	0	0
Group 5	2	Panda/Dragon	1	Panda/dragon
Group 6	2	Panda Cat	1	Cat/dragon

Table 3 – Presence of animals, antagonists, conflicts in the written stories

Story 3 had 2 conflicts (panda and dragon/ cat and dragon); Story 5 had 1 conflict (panda and dragon); Story 6 had 1 conflict (panda and cat) (see table 3). Like in children's drawings the animals and the antagonists played a central role in children's stories. These results are in line with the findings from children's drawings.

DISCUSSION

We presented the results of an investigation looking at a collection of 20 drawings produced by children after an intervention with a storytelling authoring tool that took place at school during regular classes. The results showed that by looking at children's drawings we were able to assess children's engagement with the tool. According to the Grammar of Visual Design, aspects that revealed children's engagement were the level of detailing and personalization of the story elements, the depiction in the foreground, the choice of vibrant colours, and the number of representations (see table 1, 2). Our analyses indicates that the antagonists and the animals were the elements that the children found most appealing and were represented in 19 of the drawings. The landscapes have also shown to provide a significant background context to children's representations suggesting their relevance to the creation of the story world. Surprisingly, the weather conditions seem also to be an appealing element for children.

The most depicted interactions were the conflicts, with the antagonists frequently represented as the most powerful element. An analysis of the elements and the actions (plots) present in children's written stories confirmed similar preferences, with the animals being present and fighting each other in most of the stories.

These findings support our investigation about the strengths of using drawings as an evaluation method to assess children's engagement with technology. By looking at children's drawings through the lens of the Grammar of Visual Design, we were able to reduce subjective interpretations of children's drawings.

As such, this work adds evidence to the body of knowledge that seeks to validate more reliable methods to assess children's opinion in user studies.

STRENGTHS OF USING DRAWINGS AND THE GRAMMAR OF VISUAL DESIGN

Drawings are a familiar way for children to express themselves [12,13,14,16]. By using drawings, we avoid confronting children with expressing their views and opinions trough words. As research has shown, depending on age and cognitive development, children may have difficulties to clearly communicate their thoughts, feelings, and opinions trough words [2,10,14].

Drawing provides children an open space to freely express themselves [14], whereby new and unexpected insights can emerge (e.g., in our study one of the unexpected results was the relevance of the background and the weather conditions for the children).

The *Grammar of Visual Design* [11] is an acknowledged approach that provided a framework to guide the analyses of children's drawings. Although, we are aware that there is always a degree of subjectivity in the interpretation of children's drawings, the framework allowed for a more rigorous analyses of children's drawings helping to reduce subjective interpretation.

INSIGHTS AND FUTURE DEVELOPMENT

The study provided valuable insights for the development of further story apps for children. For instance, we noticed that the magical objects and the musical instruments were less popopular among the children as the animals and the antagonists. In future developments we could prioritize the inclusion of animal and characters in the story world. Also, as children excelled in the representation of the weather conditions and the landscapes, In future work we will include more weather elements.

In future work we intend to continue using drawings to assess and measure different aspects of children's interactions with technology. We believe this initial exploration provides a starting point for further investigations into user studies involving children. As such, this work adds evidence by expanding on the corpus of work focused on measuring the amount of fun that the children experience by interacting with technology [24, 25, 26] while seeking to validate reliable methods to assess children's opinion in user studies.

SELECTION AND PARTICIPATION OF CHILDREN

Researchers obtained the ethical clearance from their institution, then contacted the school for their approval. Sequentially researchers ensured that parents were informed about the activity, for them to consent to their children participating in the study. Researchers also made sure children were aware their participation was on a voluntary basis, and so they were free to drop out of the study anytime they felt so.

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- CEDH – Research Centre for Human Development (Ref. UIDB/04872/2020).

REFERENCES

[1] S. Airey, L. Plowman, D. Connolly, and R. Luckin. 2002. Rating children's enjoyment of toys, games and media. 3rd World Congress of the International Toy Research Association on Toys, Games and Media, London.

[2] A. Anning, and K. Ring. 2004. Making Sense of Children's Drawings. Open University Press, McGraw-Hill Education, Berkshire, Great Britain.

[3] A. Bell. 2007. Designing and testing questionnaires for children. Journal of Research in Nursing 12, 5: 461–469. https://doi.org/10.1177/17449871079616

[4] L. Botturi. 2021. "Draw the internet": A visual exploration of how children imagine an everyday technology. Journal of Media Literacy Education, 13(3), 35–48.

[5] M. Coquet. 2000. A Narrativa Gráfica: uma estratégia de Comunicação de Crianças e de Adultos. CESC-University of Minho, Braga.

[6] C., Giang, L., Addimando, L. Botturi. Have You Ever Seen a Robot? An Analysis of Children's Drawings Between Technology and Science Fiction. Journal for STEM Educ Res (2023). https://doi.org/10.1007/s41979-023-00098-6

[7] M. Guha, A. Druin, G. Chipman, J. A. Fails, S. Simms, and A. Farber. 2004. Mixing Ideas: A New Technique for Working with Young Children as Design Partners. In Proceedings of the Conference on Interaction Design and Children: building a community (IDC'04). Maryland: ACM press, pp. 35-42.

[8] L. Hall, C. Hume, and S. Tazzyman. 2016. Five degrees of happiness: effective smiley face Likert Scales for evaluating with children. In Proceedings of the 15th International Conference on Interaction Design and Children - IDC '16, 311–321. https://doi.org/10.1145/2930674.2930719

[9] L. Hanna, K. Risden, and K. J. Alexander. 1997. Guidelines for usability testing with children. Interactions, 4(5), 9-14.

[10] E. Koppitz. 1983. Psychological evaluation of human figure drawings by middle school pupils. New York: Grune & Stratton.

[11] G. Kress and T. Van Leeuwen. 2006. Reading images: the grammar of visual design. London; New York: Routledge.

[12] V. Lowenfeld and W. Brittain. 1975. Creative and Mental Growth, 6th ed. Macmillan, New York.

[13] G. Luquet. 1927. Le Dessin Enfantin. Librairie Felix Alcan, Paris. Also available online: http://luquet-archives.univparis1.fr/document.php?domaine=psychologie&fichier=802&photo=ledessinenfantin-005.jpg&lg=fr

[14] J. Malkiewicz and M. L. Stember. 1994. Children's Drawings: A Different Window. In: Art & Aesthetics in Nursing, P. L., Chinn, J., Watson (eds.), University of Colorado Health Sciences, Center for Human Caring. New York: National League for Nursing Press, pp. 263-290.

[15] P. Mertala. 2019. Young children's conceptions of computers, code, and the Internet. International Journal of Child-Computer Interaction, 19, 56–66. https://doi.org/10.1016/j.ijcci.2018.11.003.

[16] C. Painter, J. Martin, and L. Unsworth. 2012. Reading Visual Narratives: Image Analysis of Children's Picture Books. Sheffield, UK: Equinox.*f*

[17] Y., Sekhavat. 2017. Behavior Trees for Computer Games, International Journal on Artificial Intelligence Tools 26, 02. https://doi.org/10.1142/S0218213017300010

[18] C. Silva, C. Prandi, M. Ferreira, V. Nisi, and N. Jardim Nunes. 2019. See the World Through the Eyes of a Child: Learning from children's cognitive maps for the design of child-targeted locative systems. In Proceedings of the 2019 on Designing Interactive Systems Conference (DIS '19). Association for Computing Machinery, New York, NY, USA, 763–776. https://doi.org/10.1145/3322276.3323700

[19] C., Sylla, P., Branco, C., Coutinho, E., Coquet. 2012. TUIs vs. GUIs: comparing the learning potential with preschoolers. Personal and Ubiquitous Computing, 16(4), 421-432.

[20] C. Sylla, E. Márquez Segura, A. DeWitt, A. Sabbir Arif, and E. Brooks. 2019. Fiddling, Pointing, Hovering and Sliding: A Study of Embodied Actions with Three Evaluation Tools for Children. In Proceedings of the Annual Symposium on Computer-Human Interaction in Play, CHI Play '19, pp. 59-72, Barcelona, Spain, October 22-25. doi>10.1145/3311350.3347170

[21] Valguarnera, S., Sylla, C., Landoni, M. 2022. Magic and Reality: what children's drawings tell us about their perception of technology. In Interaction Design and Children (IDC '22). Association for Computing Machinery, New York, NY, USA, 498–503. https://doi.org/10.1145/3501712.3535295

[22] D. Xu, E. Mazzone, and S. MacFarlane. 2006. In search for evaluation methods for children's tangible technology. In Proceedings of the Conference on Interaction Design and Children (IDC'06). Tampere, Finland: ACM Press, pp. 171-172.

[23] D. Xu, J. Read, and R. Sheehan. 2008. In Search of Tangible Magic. In The 22nd BCS British - HCI. Liverpool, UK. Also available online: http://www.chici.org/references/in_search_of_tangible_magic.pdf

[24] D. Xu, J. Read, G. Sim, and B. McManus. 2009. Experience it, draw it, rate it: capture children's experiences with their drawings. In Proceedings of the 8th International Conference on Interaction Design and Children, (IDC'09). Como, Italy: ACM Press, pp. 266-270.

[25] B. Zaman, V. Abeele, and D. De Grooff. 2013. Measuring product liking in preschool children: an evaluation of the Smileyometer and This or That methods. International Journal of Child-Computer Interaction 1, 2: 61–70. https://doi.org/10.1016/j.ijcci.2012.12.001.