# Research on Children's Chinese Character Structure Learning and Orthographic Awareness Promotion Based on TUI Interaction

Sisi Ma

Zhejiang University of Technology, Hangzhou 310014, China

1206835648@qq.com

**Abstract.** With the advancement of basic education reform and the implementation of the "Double Reduction" policy, fostering structural comprehension and orthographic awareness in Chinese character learning for lower primary grades has become a research hotspot. This study designed and compared the effects of a tangible user interface (TUI) learning mode based on embodied interaction and a traditional learning mode on the orthographic awareness of first-grade children. In a controlled experiment, children completed a pretest-learning-posttest procedure for an orthographic judgment task, with behavioral and eye-tracking data collected simultaneously. The results showed that the TUI group achieved a significantly greater improvement in orthographic judgment accuracy, with their sensitivity to component form and position errors in Chinese characters enhanced markedly.

**Keywords:** Orthographic Awareness; Chinese Character Structural Cognition; Tangible User Interface (TUI); Children’s Literacy Learning.

## 1 Introduction

In recent years, the state has continuously promoted the reform of basic education, emphasizing the systematic and structural understanding of Chinese character teaching in the lower primary grades. *Curriculum Standards for Chinese Language in Compulsory Education* highlights the need to focus on the inherent connection between the rules of character formation and Chinese character culture [1]. Research has shown that children's difficulties in learning Chinese characters do not lie in individual strokes perse, but in their insufficient ability to comprehend character structural forms, which impairs their character learning efficiency, memory retention, and meaning construction [2]. In the field of Chinese character cognition, orthographic awareness is regarded as the sensitivity to the structural rules, component legality, spatial positions, and other characteristics of Chinese characters. Its developmental level is closely associated with children’s character learning speed, structural identification ability, and writing accuracy [3]. Traditional teaching mostly relies on holistic character recognition and writing practice, lacking systematic guidance on component semantics and structural hierarchy,



S. Shamsudin et al. (eds.), *Proceedings of the 4th International Conference on Language and Cultural Communication (ICLCC 2026)*, Advances in Social Science, Education and Humanities Research 1025,
https://doi.org/10.2991/978-2-38476-597-3_18

which makes it difficult to stimulate children’s active analysis of character structural forms.

Considering At the same time, the Tangible User Interface (TUI) interaction mode emphasizes the manipulation of digital information through physical operations, providing embodied experiences and multi-sensory feedback. TUI materializes abstract knowledge in a visible and tangible way, which facilitates children’s conceptual integration and active participation[4]. Given that the disassembling and reorganizing of Chinese characters are naturally compatible with the operational characteristics of TUI, the introduction of TUI into children’s Chinese character learning holds significant application potential. This study aimed to explore the application of TUI interaction design in Chinese character structure learning for lower primary grades.

## 2 Theoretical Overview

Existing research on children’s Chinese character learning has mostly focused on teaching approaches such as holistic memorization, repetitive writing, and phonological reinforcement [5]. Traditional classroom teaching also centers on presenting complete characters and teacher explanation, and consolidates character form memory through repeated reading, tracing, and copying. While such methods can improve the efficiency of short-term memorization, they lack explicit guidance on the internal structure of Chinese characters, leading children’s character form memory to remain at the level of overall outline or individual strokes, and hindering their systematic understanding of character component composition and structural rules.

To address these shortcomings, some studies have attempted to introduce component-based teaching, explanations of character formation rules, and structural classification training to guide children in paying attention to radicals and their semantic functions . Although such methods have promoted children’s understanding of the orthographic formation rules of Chinese characters to a certain extent, they still rely primarily on teacher explanations and static examples in practical teaching, leaving children in a passive receptive state and lacking active manipulation and exploration of structural relationships. Thus, how to support children in constructing the cognition of Chinese character structure through more participatory approaches has become a key issue in current research.

TUI emphasizes the manipulation and comprehension of digital information through physical operations, whose core characteristic lies in transforming abstract concepts into operable and perceivable physical objects. Existing studies have shown that TUI can reduce cognitive abstraction through manual manipulation, spatial layout and multi-sensory feedback, and facilitate learners' understanding of complex structural relationships [6]. In children's learning contexts, TUI is particularly suitable for supporting the knowledge construction process characterized by disassembly and recombination. Chinese characters themselves have distinct component hierarchies and spatial structural features, and their orthographic formation logic is highly consistent with the physical assembly and spatial organization emphasized by TUI, which provides a natural fit for the application of TUI in Chinese character learning.

From the perspective of orthographic awareness, children's ability to identify component legality, understand component position constraints, and judge structural anomalies constitutes a key marker of their Chinese character cognitive development [7]. Through the graspability and spatial positioning of physical components, TUI enables children to naturally attend to orthographic rules such as which components can be used and where components should be placed during operation, thus transforming abstract structural constraints into perceivable operational feedback. Therefore, TUI not only provides a new interaction mode but also cognitively supports the formation and internalization of orthographic awareness, offering an effective research approach for exploring the mechanisms of children's Chinese character structure learning.

# 3 Formative Study

Prior to the official experimental study, this research systematically sorted out the actual demands in children's Chinese character learning scenarios through a formative study, and transformed these demands into actionable TUI design strategies, thus providing theoretical and practical foundations for the design and development of the interactive prototype used in subsequent experiments. The formative study of this research focused on two core questions: first, sorting out the objectives, approaches, and existing difficulties of children's Chinese character learning from the perspectives of teachers and parents; second, how to translate the above demands into embodied interaction design elements that support Chinese character structure learning.

First, this study adopted a semi-structured interview method and conducted interviews with 5 Chinese language teachers and 7 parents of children ranging from senior kindergarten to the third grade of primary school. Interviews with teachers focused on Chinese language teaching content, Chinese character teaching methods for different grades, and common problems encountered by children in understanding character structural forms; interviews with parents focused on the actual forms of Chinese character learning in family settings, experiences with learning products that have been used or purchased, and children's interest feedback on Chinese language learning and related learning products. Through the collation and induction of interview data, this study extracted a total of 13 key factors influencing the experience of Chinese character learning from five dimensions: learning objectives, learning processes, interaction modes, feedback forms, and emotional experiences, thus initially outlining the demand structure of learning products for children's Chinese character learning.

On this basis, this study further developed a Kano questionnaire to evaluate the importance and satisfaction of the aforementioned 13 demand factors. The questionnaire was distributed to primary school Chinese teachers with experience in Chinese character teaching, as well as parents of kindergarten and lower primary grade children who take on tutoring responsibilities at home, with a total of 181 valid questionnaires collected. After Kano analysis and requirement prioritization, high-priority requirements served as the core functional design of the product.

Finally, to achieve a systematic translation from demand description to design operability, this study introduced the tangible interaction analysis framework proposed by

Hornecker & Buur to conduct a demand-design element mapping analysis on the high-priority demands [8]. By mapping the demands to four interaction themes—physical manipulation, spatial interaction, embodied convenience, and expressive representation—this study extracted four categories of TUI design strategies: structural visualization and spatial construction, action-driven embodied learning, multimodal real-time feedback, and semantic connection and situational expression. A TUI prototype was designed based on these strategies and adopted as the learning product for the TUI group in the experimental study, the use of which is illustrated in Figure 1.

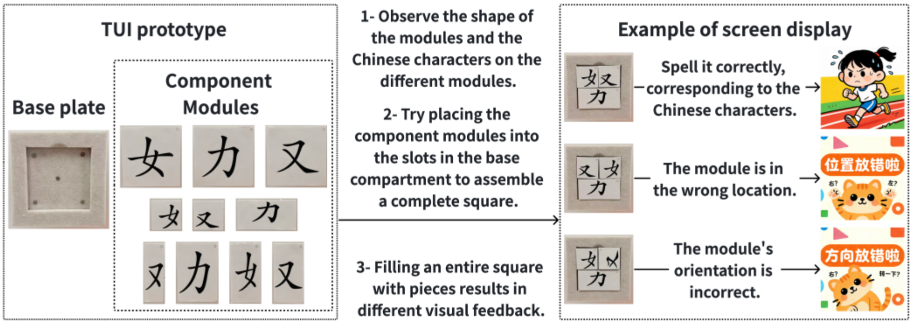


**Fig. 1.** Instructions for the TUI Prototype

## 4 Empirical Study

### 4.1 Experimental Objectives and Hypotheses

Through a comparative experiment, this study aimed to explore the facilitative effect of a learning mode based on structural comprehension and component manipulation (the experimental group) on children's Chinese character orthographic awareness. The specific hypotheses were as follows: (1) The teaching method featuring structural construction and physical manipulation can effectively improve children's ability to identify and diagnose the component forms and structural relationships of Chinese characters; (2) Different learning modes will lead to differentiated visual processing patterns in children during the orthographic judgment task. Based on these hypotheses, the study designed a pretest-learning-posttest procedure to compare the effects of TUI-based interactive learning and traditional learning on the orthographic ability of first-grade children.

### 4.2 Experimental Procedure

This study adopted a controlled experimental design, in which 24 first-grade children were randomly assigned to the TUI group (applying the TUI physical interaction learning mode) and the traditional group (adopting the traditional writing-based learning mode), with 6 boys and 6 girls in each group. All participants had normal visual acuity and no learning disabilities. A Tobii Pro X3-120 eye tracker was used in the experiment to record children's visual attention allocation during the orthographic judgment task.

As illustrated in Figure 2, the experimental procedure consisted of four phases: a testing phase, an explanation-learning phase, a comprehensive practice phase, and a subjective evaluation phase. The testing phase was divided into pretest and posttest, both of which adopted the identical orthographic judgment task: children judged whether 55 test items were legitimate Chinese characters in sequence. These 55 items were categorized into five types: genuine characters, rule-compliant pseudocharacters, non-characters with component errors, non-characters with component misplacement, and graphic distractors. Pseudocharacters were constructed by exchanging components of genuine characters; non-characters with component errors were created by introducing stroke errors into the radicals and components of characters; non-characters with component misplacement were formed by placing valid components in incorrect positions; graphic distractors were meaningless line symbols. Accuracy rates, reaction times, and eye-tracking data were recorded for both the pretest and the posttest.

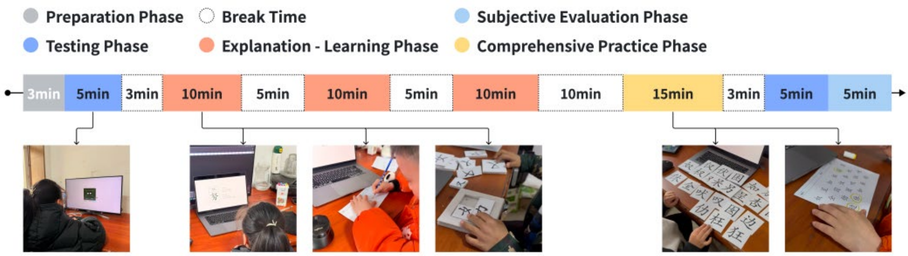


**Fig. 2.** Experimental Procedure

In the explanation-learning phase, the researcher used PPTs to explain to the children the character forms, meanings, component definitions, and combination rules of three key teaching characters: 努， 保， 逛. The criteria for character selection were diverse structural types alongside concise and complementary components, and the ability to generate new characters through component recombination. Subsequently, the two groups completed distinct learning tasks respectively: the traditional group performed component-based writing practice, namely, copying the structure of each teaching character in the order of its components with a pencil; the TUI group assembled the teaching characters using physical component modules on a custom-made base board.

The comprehensive practice phase comprised a recall-reconstruction task and an independent classification task, designed to examine children's transfer ability of structural knowledge acquired during the learning phase. In both tasks, the materials for the traditional group were presented in a 2D format, while those for the TUI group were presented as 3D physical objects. Finally, in the subjective evaluation phase, a smiley face scale (1–5 points) was adopted to collect children's feedback on their interest in and satisfaction with the two learning modes.

## 4.3 Data Source

**Orthographic Judgment Performance.** The overall accuracy rates and the accuracy rates for different character types of the participants in the traditional group and the TUI group in the orthographic judgment task are presented in Table 1. After the intervention, the judgment performance of the TUI group was significantly superior to that of the traditional group. Overall, the total accuracy rate of the traditional group only increased from 59.09% to 63.34%, whereas that of the TUI group rose from 58.49% to 76.06%. When broken down by stimulus type, the TUI group achieved a higher growth rate in accuracy across all categories, especially for non-characters with component misplacement: the accuracy rate of the traditional group merely increased from 50.00% to 55.00%, while that of the TUI group jumped from 41.67% to 76.67%. For graphic distractors, both groups achieved nearly full marks (>95%) with little change in accuracy. These results indicate that the TUI group made greater progress in identifying subtle structural differences, with the embodied learning mode significantly enhancing their orthographic judgment ability. Consistent with their higher structural reproduction accuracy in the recall-reconstruction task, this suggests the TUI group had formed stable structural representations during learning.

**Table 1.** Accuracy Rates of Different Character Types and the Total in the Orthographic Judgment Task Between the Two Groups.

| Character Type | Traditional Group | | | | | TUI Group | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pretest | | Posttest | | MD | Pretest | | Posttest | | MD |
| | M(%) | SD | M(%) | SD | | M(%) | SD | M(%) | SD | |
| a | 61.33 | 0.138 | 65.56 | 0.154 | +4.23 | 58.89 | 0.181 | 80.00 | 0.202 | +21.11 |
| b | 57.67 | 0.248 | 60.00 | 0.276 | +2.33 | 60.00 | 0.228 | 76.67 | 0.242 | +16.67 |
| c | 35.67 | 0.223 | 36.67 | 0.242 | +1.00 | 36.67 | 0.294 | 45.00 | 0.243 | +8.33 |
| d | 50.00 | 0.237 | 55.00 | 0.259 | +5.00 | 41.67 | 0.264 | 76.67 | 0.163 | +35.00 |
| e | 96.67 | 0.052 | 98.33 | 0.041 | +1.66 | 95.00 | 0.084 | 100.0 | 0.000 | +5.00 |
| Total | 59.09 | 0.019 | 63.34 | 0.021 | +4.25 | 58.49 | 0.027 | 76.06 | 0.054 | +17.57 |

Note. a = Genuine Characters, b = Pseudocharacters, c = Non-characters with Component Errors, d = Non-characters with Component Misplacement, e = Graphic Distractors

**Table 2.** Results of Mann-Whitney U Test for Eye-tracking Metrics in the Pseudocharacter Condition Before and After the Test Between the Two Groups.

| Testing Phase | AOI | Eye-tracking Metrics | Traditional Group | | TUI Group | | U | p | r |
|---|---|---|---|---|---|---|---|---|---|
| | | | M | SD | M | SD | | | |
| Pretest | Radical | Fixation Duration Ratio | 0.336 | 0.045 | 0.315 | 0.021 | 73 | 0.485 | 0.202 |
| | | Fixation Count Ratio | 0.359 | 0.042 | 0.353 | 0.019 | 67 | 0.936 | 0.023 |
| | Affix | Fixation Duration Ratio | 0.664 | 0.045 | 0.685 | 0.021 | 63 | 0.485 | 0.202 |
| | | Fixation Count Ratio | 0.641 | 0.042 | 0.647 | 0.019 | 69 | 0.936 | 0.023 |
| | Total | Visit Count | 3.217 | 0.757 | 3.233 | 0.606 | 67 | 0.936 | 0.023 |
| Posttest | Radical | Fixation Duration Ratio | 0.362 | 0.043 | 0.361 | 0.014 | 72 | 0.589 | 0.202 |
| | | Fixation Count Ratio | 0.392 | 0.051 | 0.397 | 0.048 | 72 | 0.589 | 0.023 |
| | Affix | Fixation Duration Ratio | 0.638 | 0.043 | 0.639 | 0.014 | 64 | 0.589 | 0.202 |
| | | Fixation Count Ratio | 0.609 | 0.051 | 0.603 | 0.048 | 64 | 0.589 | 0.023 |
| | Total | Visit Count | 3.217 | 0.535 | 3.433 | 0.561 | 63 | 0.519 | 0.023 |

Note. *p<0.05, *p<0.01, p<0.001; r: trivial (r<0.10), small (0.10–0.30), medium (0.30–0.50), large (r ≥ 0.50).

**Eye Movement Processing Characteristics.** To further explore the changes in the judgment process, eye movement metrics were introduced to conduct a comparative analysis of visual attention distribution across three character types. For pseudocharacters, the results of the Mann-Whitney U test on pretest and posttest eye movement metrics of the two groups are presented in Table 2. In the posttest, no significant differences were found between the TUI group and the traditional group in fixation duration, fixation count, and visit count on the key Areas of Interest (AOIs). This result indicated that when there were no obvious structural conflicts in character forms, children in both groups could rely on the global structure to complete judgments rapidly, and the learning mode had a relatively limited impact on their visual processing strategies.

**Table 3.** Results of Mann-Whitney U Test for Radical AOI Eye-tracking Metrics in the Non-character with Component Errors Condition Before and After the Test Between the Two Groups.

| Testing Phase | Eye-tracking Metrics | Traditional Group | | TUI Group | | U | p | r |
|---|---|---|---|---|---|---|---|---|
| | | M | SD | M | SD | | | |
| Pretest | Fixation Duration | 0.336 | 0.060 | 0.342 | 0.023 | 65 | 0.699 | 0.112 |
| | Fixation Duration Ratio | 0.362 | 0.030 | 0.359 | 0.007 | 71 | 0.699 | 0.112 |
| | Fixation Count | 2.200 | 0.438 | 2.517 | 0.511 | 62 | 0.334 | 0.279 |
| | Fixation Count Ratio | 0.411 | 0.046 | 0.359 | 0.014 | 30 | 0.065 | 0.533 |
| | Visit Count | 1.533 | 0.455 | 1.633 | 0.480 | 65 | 0.747 | 0.093 |
| Posttest | Fixation Duration | 0.444 | 0.075 | 0.674 | 0.036 | 16 | 0.002** | 0.885 |
| | Fixation Duration Ratio | 0.427 | 0.045 | 0.518 | 0.017 | 14 | 0.002** | 0.885 |
| | Fixation Count | 2.883 | 0.711 | 3.567 | 0.418 | 46 | 0.089 | 0.491 |
| | Fixation Count Ratio | 0.432 | 0.096 | 0.541 | 0.022 | 27 | 0.026* | 0.643 |
| | Visit Count | 1.750 | 0.243 | 1.867 | 0.472 | 67 | 0.936 | 0.023 |

Note. *p<0.05, *p<0.01, p<0.001; r: trivial (r<0.10), small (0.10–0.30), medium (0.30–0.50), large (r ≥ 0.50)

For non-characters with component errors, the radical components constituted the only illegal regions, and the test results are presented in Table 3. There were no significant differences between the two groups in the pretest for this category; however, in the posttest, the TUI group exhibited a significant increase in fixation duration on the Radical AOIs, with both the proportion of fixation duration and the proportion of fixation count significantly higher than those of the traditional group ($p < 0.01$). This indicated that after TUI-based learning, children could locate potential erroneous components more rapidly when judging non-characters and conduct more in-depth visual processing of these regions. In contrast, children in the traditional group still tended to rely on affixes or global outlines as their primary judgment criteria, with a limited increase in sensitivity to the legality of radical components.

For non-characters with component misplacement, the forms of the two components were both valid but their positions were exchanged, which required children to compare the positional relationship between them; the test results are presented in Table 4. In the posttest, the TUI group showed significantly higher fixation duration and fixation count on the Radical AOIs, as well as significantly higher visit count between Radical and Affix AOIs, than the traditional group ($p < 0.01$). This indicated that children in the TUI group exhibited a more pronounced comparison strategy during the judgment process, namely, confirming the structural relationship by repeatedly shifting their gaze between multiple key components. This processing strategy was also reflected in their performance in the learning tasks: children in the TUI group were more inclined to actively compare component positions and complete structural recombination without prompt conditions. In contrast, the traditional group still showed a preference for Affix AOIs, with their overall processing mode remaining centered on locally dominant components.

**Table 4.** Results of Mann-Whitney U Test for Eye-tracking Metrics in the Non-character with Component Misplacement Condition Before and After the Test Between the Two Groups.

| Testing Phase | AOI | Eye-tracking Metrics | Traditional Group | | TUI Group | | U | p | r |
|---|---|---|---|---|---|---|---|---|---|
| | | | M | SD | M | SD | | | |
| Pretest | Radical | Fixation Duration | 0.367 | 0.046 | 0.363 | 0.056 | 71 | 0.699 | 0.112 |
| | | Fixation Count | 2.450 | 0.418 | 2.467 | 0.450 | 66 | 0.871 | 0.047 |
| | | Visit Count | 1.483 | 0.376 | 1.500 | 0.179 | 66 | 0.872 | 0.047 |
| | Affix | Fixation Duration | 0.576 | 0.065 | 0.581 | 0.055 | 67 | 0.873 | 0.046 |
| | | Fixation Count | 3.350 | 0.378 | 3.367 | 0.393 | 67 | 0.936 | 0.023 |
| | | Visit Count | 1.533 | 0.327 | 1.683 | 0.462 | 65 | 0.686 | 0.117 |
| Posttest | Radical | Fixation Duration | 0.440 | 0.063 | 0.629 | 0.015 | 10 | 0.002** | 0.885 |
| | | Fixation Count | 2.900 | 0.420 | 3.983 | 0.232 | 12 | 0.002** | 0.885 |
| | | Visit Count | 1.883 | 0.376 | 2.500 | 0.110 | 13 | 0.009** | 0.748 |
| | Affix | Fixation Duration | 0.609 | 0.108 | 0.707 | 0.022 | 57 | 0.180 | 0.387 |
| | | Fixation Count | 3.717 | 0.492 | 4.150 | 0.295 | 48 | 0.106 | 0.466 |
| | | Visit Count | 1.767 | 0.266 | 2.350 | 0.251 | 14 | 0.007** | 0.772 |

Note. $*p<0.05$, $*p<0.01$, $p<0.001$; r: trivial ($r<0.10$), small (0.10–0.30), medium (0.30–0.50), large ($r \geq 0.50$).

Synthesizing the eye movement results across the three stimulus types, it can be found that the effect of TUI-based learning on children's visual processing strategies exhibited distinct selectivity: it had a minor impact on the processing of structurally legitimate pseudocharacters, yet significantly altered children's attention allocation patterns under the non-character conditions involving judgments of component legality and positional relationships. In the posttest, children in the TUI group could locate erroneous components more effectively and complete judgments by repeatedly comparing the relationships between components. This result verifies the mechanism of TUI in promoting the development of children's Chinese character orthographic awareness from the perspective of processing procedures.

## 5 Conclusion

This study verified the facilitative effect of TUI interaction on first-grade children's Chinese character orthographic awareness through experimental comparison. Compared with the traditional learning mode, the TUI group showed significantly greater improvement in orthographic judgment accuracy, especially for characters with complex structures. Eye-tracking data revealed the underlying cognitive mechanism: TUI-based learning enhanced children's sensitivity to illegal components (with more visual attention allocated to erroneous parts) and fostered a balanced, iterative comparative strategy for component position analysis. In summary, the embodied interactive experience stimulated children's attention to Chinese character internal structures and structural rule summarization, thereby improving orthographic awareness. The findings offer new insights for lower primary Chinese education: TUI-based embodied interaction can break traditional static teaching limitations and enhance children's active participation. Future research may optimize TUI tool design, expand sample size and teaching content scope, and examine its long-term effectiveness in practical settings.

## References

1. Ministry of Education of the People's Republic of China. (2022). *Compulsory education Chinese curriculum standards (2022 edition)* [S]. Beijing: Beijing Normal University Press.
2. Li, B. H., & Wang, X. (2024). Problems and countermeasures of Chinese character recognition teaching in lower primary grades under the background of the new curriculum standard [J]. *Contemporary Theory and Practice of Education*, 16(4), 8-13.
3. Li, H., Peng, H., & Shu, H. (2006). The germination and development of Chinese orthographic awareness in Chinese-speaking children [J]. *Psychological Development and Education*, 22(1), 35-38.
4. Voutetaki, M. E. (2024). Application and assessment of an experiential deformation approach as a didactive tool of truss structures in architectural engineering [J]. *Education Sciences*, 14(4), 354.
5. Liu, J. W. (2022). The importance and optimization strategies of Chinese character teaching in primary schools: A review of *Theories and methods of Chinese character teaching* [J]. *Language Planning*, (2), A2.
6. Faella, P., Digennaro, S., & Iannaccone, A. (2025). Educational practices in motion: A scoping review of embodied learning approaches in school [J]. *Frontiers in Education*, 10, 1568744.
7. Ehri, L. C. (1992). Reconceptualizing the development of sight word reading and its relationship to recoding [A]. In R. J. Tierney & J. W. Antony (Eds.), *Reading acquisition* (pp. 107-143). Hillsdale, NJ: Lawrence Erlbaum Associates.
8. Hornecker, E., & Buur, J. (2006). Getting a grip on tangible interaction: a framework on physical space and social interaction. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 437–446.