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TITLE

Enhancing Data Visualization Literacy in Elementary Children with Tangible User Interfaces (TUIs)

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STEM Learning through Tangible User Interfaces (TUIs)

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Enhancing Data Visualization Literacy in Elementary Children with Tangible User Interfaces (TUIs)

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Tangible User Interfaces (TUIs), a term first coined by Hiroshi Ishii at the MIT Media Lab in 1997, blend physical objects and manipulatives with digital information to enable embodied and experiential learning of virtual data. Technology is central to TUIs, as they originated in the field of computing and evolved with our understanding of computer applications. In the field of education, TUIs integrate and employ visual, auditory and tactile technologies to present information in multiple formats to support multimodal learning. Their pedagogical foundation can be traced to Piaget's constructionist approach to learning, which suggests that learners build a deeper understanding of abstract concepts through direct engagement with physical artifacts[3].

Thus, the three basic tenets of TUIs— 'technology', 'multiple representations' and 'learning by doing'—make them a potent tool to promote data visualization literacy (DVL) in K-5 children. DVL enables children to interpret complex information by interacting with data through visual and symbolic representations such as graphs, charts and maps. The multimodal capacities of TUIs complement the aim of DVL by allowing a more natural and concrete way for children to interact with the physicalized form of data they are working with. The embodied, playful nature of learning with TUIs, naturally combined with the interactive and visually engaging approach of DVL, complement each other in informal learning environments, providing children with a more approachable entry point to becoming data-literate adults.

The research surrounding TUI in education focuses on affective dimensions of learning — motivation to engage, pleasure taken in doing, the possibility of liking a task and so on[1]. This results in research outcomes emphasizing learner engagement and interest rather than assessing quantitative or cognitive learning outcomes, as shown in the examples later in this paper. This does not diminish the proven positive impacts of TUIs on cognitive development and schemata assimilation and accommodation as they provide children with "objects to think with"[1]. In the broader educational landscape, TUIs offer a new perspective on learning by extending it beyond traditional classrooms, encouraging educators to leverage the impact of embodiment on cognition, and guiding the design of effective scaffolds and learning environments.

The shared emphasis of TUIs and DVL on making abstract data more accessible and understandable significantly impacts the learning sciences. In the 21st century, especially post-pandemic and with the rise of natural disasters, we are constantly engaging with big data. However, humans collectively struggle to derive meaning from abstract data, as evident by the rampant misinformation and critical issues like science denial that surround us. Data literacy enhances cognition by developing critical thinking, problem-solving skills and facilitating interdisciplinary inquiry into the challenges of the information-driven society we live in. Complementing this, TUIs provide a new direction to the design of children's educational technologies[4] to be more adaptive and compassionate towards how children naturally learn.

Most current DVL tools are typically facilitated by an educator and employed within formal learning environments[8]. Due to their focus on the body in action, the most natural applications of TUIs are found in studios, workshops, or playgrounds, as opposed to traditional classrooms[1]. The integration of TUIs into DVL has helped bridge the gap by extending data literacy beyond the classroom. To inculcate data visualization skills, successful applications of TUIs have focussed on supporting action-based learning through active play and games. Two such informal play-based applications of TUIs to improve DVL are 'Data is Yours' and 'Diagram Safari'.

Diagram Safari[5] is an educational game designed to foster data literacy among children 9 to 11 years old to help them interpret bar charts and pie charts, through interacting with "playable data". Players guide an armadillo through levels that get incrementally difficult, by assigning data blocks to bars, solving puzzles and are quizzed to reinforce learning. A preliminary evaluation with 23 children showed that the game was well received as it approached a topic of interest and motivated continuous engagement with appropriate challenges. The feedback was focused on game design and playability rather than children's learning curve.

Data is Yours[6] is a do-it-yourself toolkit designed to teach children DVL through play and curiosity. Using everyday materials like cardboard and paper, children assemble the kit, collect data, create a paper template, and then construct a chart panel to represent three different interactive visualizations (bar, line, pie). Through its three themes of Accommodation, Engagement and Scaffolding, and Embodied learning, it encourages hands-on exploration of not just data but also the kit itself, imbibing a sense of ownership in learners. The results showed how children and educators envisioned the toolkit being used in different contexts such as museums and even homes. Children showed their willingness to try again despite the challenges they faced initially. Children with prior data visualization knowledge found the toolkit useful for everyday life, while others saw it as an engaging introduction to visualizing data. Similar to *Diagram Safari*, *Data is Yours* focuses on affective learning, ignoring formal DVL assessment.

Unlike *Diagram Safari* where children interact with predefined data, *Data is Yours* allows children to work with data sets that they think are important. This is also seen in the use of *Data Sculptures*[7], which encourage students to build artifacts that are personally relevant and meaningful, thus personalizing the learning. These examples highlight three guiding principles[7] when designing for DVL using TUIs — Using low-cost familiar materials for children to work with and experiment; staying low-tech to meet the learners where they are and lastly, 'creating a playground' where learners feel safe to make mistakes.

For efforts in building TUIs to support DVL to be fruitful, more focus is required in developing better methods to assess the learning outcomes of such interventions and understand how they challenge or support the skill levels of learners who are new to such technologies. The challenge lies in fully grasping the power of performative knowledge building in children[2]—how they solve problems using their bodies—and harnessing this understanding to design more effective tangible systems and spaces, each process enhancing the other for better educational outcomes. By embracing the synergy between TUIs and DVL, educators can design more intuitive, age-appropriate learning experiences that channel children's abundant energy.

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