Open Phygital Toolkits for Inclusive Science and Technology Education

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1 INTRODUCTION

The traditional education system has taught **the same scientific-technological way of thinking** to all, thus leaving many behind. That resulted in **lack of diverse perspectives** in the way science and technology (S&T) **research** and **commercialization** are currently conducted, e.g., leading to the current gender gap in S&T, in research and industry alike. To remedy the situation, many advocate enriching how **S&T education** is conducted, through **inclusive workshops with tools** for learning and doing, as done by the STEAM movement in education and championed by the MIT Media Lab (https://www.media.mit.edu/research/?filter=groups). How to do so effectively in different educational contexts remains open to investigation. We **hypothesize** that more **inclusive S&T education** requires novel **phygital toolkits**, combining and adapting physical material, open software and hardware, for broadening the range of expression means for diverse learners. The toolkits should also be **open** in that they enable for the free **exploration** of their inner working and related S&T knowledge. Moreover, in line with recent inclusive initiatives for learners, we propose that such toolkits should be used in **socio-culturally relevant design activities** for "**making and use**" and "**collective sense-making**" [2,3,4,8]. The remainder of this position paper posits how we plan to develop **open phygital toolkits** for **inclusive S&T educational** activities which are **design-oriented**, and **example prototypes** of such toolkits by authors of this paper and colleagues.

2 OUR VISION ON THE DEVELOPMENT OF OPEN PHYGYTAL TOOLKITS

Inclusive S&T activities which are design oriented, like STEAM or making workshops, aim at engaging different participants. They use **phygital** toolkits which consist of a range of tools: physical material for crafting (e.g., pens, crayon, textile), digital tools (e.g., Scratch), fabrication (e.g., 3D-printing pens) and electronic prototyping tools (e.g., Arduino, Raspberry Pi, micro:bit). Such activities strive to cater for different participants, in different educational contexts. Thereby, their toolkits should not only be **usable** by specific types of users in given educational contexts; they should also be **rapidly adaptable** to different types of users, for diverse educational contexts.

To be rapidly adaptable, **end-user development** approaches like **meta-design** suggest that toolkits should be modular, **"open, under-designed**", which can be discarded with low costs, rapidly adapted or re-purposed [9]. Under-designed solutions do not necessarily show limited capabilities, rather they are malleable and modifiable, e.g., according to the emergence of **novel possibilities through usages by different people**. This is especially true for **toolkits for children and teens**, who, compared to adults, more often come up with **creative and unexpected usages** of toolkits, in ways which cannot be predicted by adults [15]. Moreover, toolkits for inclusive S&T education should also be open in the sense of open software and hardware, which enable for their rapid appropriation, adaptation, or re-purposing **by their users**.

3 EXAMPLE TOOLKITS

Gennari, **Melonio** and colleagues from **Human Computer Interaction** at **Computer Science** developed similar toolkits, namely, **open phygital toolkits**, **SNaP** and **IoTgo**, with programmable electronics (e.g., Raspberry Pi, micro:bit), software (apps), and disposable material (e.g., paper cards), for enabling artists and design students to co-create and co-develop, besides to reflect also at a distance. For information on how those artifacts support the rapid adaptation, socially-relevant design and critical reflection, we refer the readers to [10,13]. In 2021–2022, their toolkits could be **rapidly re-adapted** to the needs of people with intellectual disabilities, children in **primary** and **secondary schools**, and used to promote **S&T education** within a **socially-relevant design-driven** process, besides to solicit **critical reflections** (e.g., [11,12]). See two examples below related to the IoTgo toolkit.

IoTgo rapidly adapted to primary schools: physical design and computing artifacts to explore and create for a science project

IoTgo rapidly adapted to secondary schools: physical design and computing for a sustainability goal

Recently, **Krik, Petti** and colleagues from **Sensing Technologies** in **Electronics** explored **additive manufacturing**, especially 2D and 3D printing with electronically functional inks, to **rapidly prototype** 2D or 3D **arbitrarily shaped electronic components** on various types of substrates, such as paper and fabric, leading to novel electronic components such as sensors [6,7,16] (Figg. a, b, c, and e), antennas [14] (Fig. g), and others [5] (Fig. d and f). These are not only adaptable and cost-effective, but also lightweight, conformable, and sustainable. Overall, their approach can be rapidly used to create **functional components for open phygital toolkits**, easily **adaptable also by their users**. For instance, **Petti**, **Krik**, and **Gennari** et al. used these components to rapidly create flexible boards for **crafting electronic paper-based** or **wearable programmable educational toolkits**, e.g., **with Arduino microcontrollers**.

CONCLUSIONS AND ACKNOWLEDGMENTS

Different voices are sought in the shaping of our open phygital toolkits. Their design is in fact a collaborative act of researchers from different fields in order to be suitable for S&T activities which aim at being design oriented. Their development also caters for the voices of learners and educators: what these express and do when using the toolkits enables for the rapid evolution of the toolkits themselves. Therefore, we acknowledge the contributions of colleagues in relation to the development of the toolkits mentioned above, e.g., Bonani, Coletti, Corni, Lugli, Matera, Morra, Rizvi, Roumelioti. We also thank all participants in activities, in particular, associations for people with intellectual disabilities, learners, students and teachers from diverse schools. The work of Krik was partly supported through the AT-NE-ST project.

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