12 Ways to Empower: Designing for Children's Digital Autonomy

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ABSTRACT

In recent years, growing research has been made on supporting children to become more autonomous in the digital environment around them. However, there has been little consensus regarding the conceptualisation of digital autonomy for children in the HCI community and how best they can be supported. Through a systematic review of autonomy-supportive designs within HCI research, this paper makes three contributions: a landscape overview of the existing conceptualisation of *Digital Autonomy* for children within HCI; a framework of 12 distinct design mechanisms for supporting children's digital autonomy, clustered into 5 categories by their common mechanisms; and an identification of 5 critical design considerations for future support of children's digital autonomy. Our findings provide a critical understanding of current support for children's digital autonomy in HCI. We highlight the importance of considering children's digital autonomy from multi-perspectives and suggest critical factors and gaps to be considered for future autonomy-supportive designs.

CCS CONCEPTS

• General and reference → Surveys and overviews; **• Human-centered computing → HCI theory, concepts and models**.

KEYWORDS

Children, Autonomy, Systematic Literature Review

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1 INTRODUCTION

While early digital computers and the Internet were designed to serve defence, academic, and business purposes, these revolutionary tools have now effectively reshaped the lived experiences of childhood [35]. Digital technologies have become so deeply embedded in children's everyday lives, providing vital access to educational, social, and entertainment experiences and resources [96]. Digital technologies are increasingly seen not as optional, but as essential for children to learn, have fun, and grow [106]. A recent Pew report showed that 60% of children in the US begin to interact with a smartphone before the age of 5, with 30% interacting with digital devices as early as ages 0-2 [29]. Children of this generation are often the early adopters of emerging services and technologies, having grown up as 'digital natives' [19, 35]. Yet, digital devices, the activities they support, and the ways children engage with such technologies are rapidly evolving. This has raised concerns and questions about how digital environments including digital apps, systems, services, platforms and more, are affecting children's well-being, and whether such environments adequately support their developmental needs [35].

A traditional supposition has been that parents and caretakers would have the greater expertise and skill set than their children, to guide their children's navigation of the digital space around them and help them learn [121]. In today's digital age, this may not always be true. Children have grown up in the digital era in a way that interacting with digital environment is almost second nature to them, and for most of them, their parents could possess far less knowledge in this domain [51, 121]. This potential reverse in expertise calls for attention on the recent line of work promoting a gradual shift from a parent/teacher-led perspective to a child-centered approach [89, 147]. Such an approach shifts philosophically from the process of *instructing*, to *supporting* children's experiences, including forms of play and exploration, which are seen as integral elements of children's development [49, 79]. Gaining self determination, including developing shared values, preferences, and self-identity are seen as essential, along with the development of children's autonomy. In fact, there has been a growing consensus on supporting children to develop autonomy online, including the ability to have and exercise a critical understanding of their digital environments, and to make their own informed choices when interacting with digital technologies and services [81, 102]. However, in the HCI community, what digital autonomy for children means and how best they can be supported is yet well-defined . We argue that this clarity is critical for the current attention on developing better support for children, helping with their skill and

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autonomy development. Furthermore, it is crucial for us to recognise the landscape of how digital autonomy for children is currently supported, and identify any design patterns or gaps of attention.

In this paper, we examine existing HCI literature discussing definitions and designs for children's digital autonomy. Our aim is to contribute an understanding of how digital autonomy for children is positioned in the current HCI community, and to identify how specific kinds of designs have been explored to support digital autonomy development in children. In order to do so, we conducted a systematic review of the use of autonomy-supportive design mechanisms in HCI research, with the goal of laying out its design space, specifically answering two research questions as follows:

- RQ1: *How does the HCI literature conceptualise digital autonomy for children?*
- RQ2: *What autonomy-supportive design mechanisms have been explored in apps and systems for children?*

Through an analysis of 68 articles from prominent HCI venues, this paper makes three contributions: first, a landscape overview of the existing conceptualisation of *Digital Autonomy* for children within HCI; second, a framework of 12 distinct design mechanisms for supporting children's digital autonomy, clustered into 5 categories by their common mechanisms; and finally, an identification of 5 critical design considerations for future support of children's digital autonomy. Our findings provide a critical understanding of current support for children's digital autonomy in HCI. We highlight the importance of considering children's digital autonomy from multi-perspectives, and suggest critical factors and gaps to be considered for future more autonomy-supportive designs.

2 BACKGROUND

2.1 Autonomy for Children: Philosophical Underpinnings

In the most general sense, autonomy refers to the state of being independent, self-governing, and free and able to exercise one's wishes without external control or influence [128]. Philosophers including Hurst Hannum [65], Ruth Lapidoth [90], Markku Suksi [134] and Yash Ghai [100] have described at least six distinct kinds of autonomy—each relating to the degree of local control and independence over specific issues, such as personal, behavioural, and functional, to the cultural, administrative, and legislative [137]. We will not elaborate on the latter, as cultural, administrative and legislative are outside the immediate concerns of the age-appropriate design of systems for children and parents. Instead, we focus on the senses relating to the personal autonomy. *Personal* autonomy pertains to an individual's capacity to make decisions and goals based on their own values, which is closely related to concepts including *behavioural* autonomy, which refers to one's capacity to take actions independently to achieve and satisfy those goals; and *functional* autonomy, which is often recognised by two commonly used definitions: so-called *propriate* motives relating to deriving and sustaining motivations relating to one's lifestyle, self-image or self-esteem [135] or, in an instrumental sense, the ability to conduct the essential activities of daily living [69]. Meanwhile, the concept of autonomy has also been studied within the context of the theory of self-determination [63, 115], which emphasises a person's ability to set goals, and take the initiative and action to achieve them. Under the lens of self-determination theory, personal autonomy is positioned as an individual's ability to engage in effective self-regulation; responding adaptively to the environment, and initiating, organising, and directing actions towards the achievement of needs [12, 24, 46]. In fact, one key element of the transition from adolescence to adulthood is the development of autonomy [68] — the stage of adolescence represents a period of dramatic change in children's capabilities for self-awareness, self-reflection, self-regulation, self-control, self-efficacy, self-determination, decision making and independence [84, 105].

The concept of autonomy, related to adolescent development, is frequently referred to and defined according to three domains: *behavioral, emotional*, and *cognitive* [17, 50, 120, 133]. On the other hand, this widely adopted categorisation of autonomy has been described in the literature in a variety of ways, focusing on domain-specific aspects. For instance, the concept cognitive autonomy is defined through "a belief one has control over his or her life" in nursing studies [34, 97]; whereas the concept is defined slightly differently towards "feelings of being able to make decisions without excessive social validation" within the psychosocial literature [41, 120, 136]. Meanwhile, literature from education focuses on the "self-determine for one's own action" aspect of cognitive autonomy [118, 132]. Based on these related yet slightly distinct conceptualisation, Spear et al. [128], through a concept analysis of the term *autonomy* in two decades of literature on the topic of autonomy across multiple disciplines, summarised and consolidated the various definitions regarding the three forms for personal autonomy for children and adolescence, specifically defining them as: *cognitive* autonomy, which refers to self-governance of the mental action or process of acquiring knowledge and understanding - to evaluate thought, to voice opinions, to make decisions independently and to self-assess [14]; *behavioural* autonomy, which is the ability to make decisions independently and more importantly, to follow through on these decisions with actions, instead of simply following along or copying others [16]; *emotional* autonomy, which refers to the ability to free oneself from emotional dependence [88]. The closer a child comes to achieving emotional autonomy, the more they learn that there are many ways to view a situation. When problems arise, emotionally autonomous children are more equipped to look for their own solutions rather than solely relying on outside influences [23, 57]. Spear et al.'s definition emphasises the multi-dimensional aspect of personal autonomy development for children, as children's development of autonomy is influenced by multiple processes, including the cognitive processes of developing judgment and decision-making, negotiating social influences from peers or parent, as well as fostering healthy behaviour development [30]. While there is no consensus on what autonomy for children should look like [125], in this paper, we use the widely accepted [27, 129] Spear et al.'s definition on personal autonomy as cognitive, behavioural and emotional autonomy as a starting point — a working definition for us to create an initial scope for distilling the more nuanced conceptualisation of digital autonomy in the existing HCI literature.

2.2 HCI Research around Designing for Children's Autonomy Online

Understanding the ways that children interact with digital technologies has been a long established area of research, both within and beyond the HCI community. In recent years, there has been a growing body of literature characterising the ways and potential impact of children's everyday interaction with the digital technologies around them [142]. At the core of these effort is to position children at the centre when interacting with digital environment, also known as "child-centred approach" [33, 54]. Safeguarding and taking care of children has been traditionally considered as the job of their parents and caretakers, positioning children as the passive recipients of their environment [139]. The supposition has been that by the time individuals become parents, most of them will successfully have completed all prior developmental tasks and will have the expertise and greater skill set than their children possess which could be used to guide their children and help them learn [121]. In today's digital age, this may not always be true. With almost every aspect of children's lives being increasingly digitalised [142], the Internet has now become seen as an essential enabler for children to learn, have fun and grow [106]. Children have grown up in the digital era in a way that interacting with digital environment is almost second nature to them. They are the masters, and for most of them, their parents could possess far less knowledgeable in this domain [51, 121].

This potential reverse in expertise calls for attention on the line of work around supporting children's drive for autonomy and identity online. The HCI community has extensive research expertise regarding designing with/for children [45, 55, 131] that support and empower them to make more informed decisions, and contributed many individual examples of human-centred systems for children that span across a variety of application domains. Design exemplars include supporting children's cognitive understanding of key computational concepts through child-friendly ways, such as Lego's Caption Safety [92] and Google's Be Internet Legends [61]; designs that support children to make sense of what happened around their data, such as Cracknell Law's situated cartoon design [80]; designs that help children comprehend the online risks around them, such as stranger danger and online inappropriate content [140]. Meanwhile, a growing body of research has been carried out regarding how to empower children with greater control over their interaction with the digital technologies, such as through having greater autonomy on their online media choices [59, 71], and dealing with various kinds of online risks [141, 152].

While research effort has been made in various domains of children's digital lives, the lack of a systematic understanding of what indeed counts towards children's digital autonomy and how designs could be implemented to support children's digital autonomy remains an open challenge in the community. This paper seeks to address this challenge through contributing an initial understanding towards the conceptualisation around digital autonomy, and ways to support the development of such digital autonomy.

3 METHOD

In order to investigate the current landscape of designing for children's digital autonomy, a systematic literature review is conducted to identify how digital autonomy has been conceptualised in existing HCI literature within the last 10 years; and how technological interventions and designs have been drawn in to support children's digital autonomy. To achieve this, we followed the PRISMA statement [108] (see Figure 1). We started with identifying a group of keywords to be used for the literature search, the sources for our literature search, and the inclusion/exclusion criteria.

3.1 Data Collection

The unit of analysis for this systematic literature review was peer-reviewed full papers from the top fifteen HCI journals and conferences on Google Scholar Ranking[1] (CHI, CSCW, HRI, Ubicomp, IJHCS, IEEE HMS, IMWUT, PACMHCI, UIST, DIS, IUI, BIT, IJHCI, TOCHI). We also included IDC proceedings due to its strong relevance to the scope of our review.

At the start, we experimented with different keywords combinations related to our research topic, and we identified the final set of keywords which gave us the best matching set of literature for further analysis. We used and combined the following terms for our search: (design OR tool OR app OR program OR game) AND (support OR empower OR inform OR autonomy OR regulation OR self- OR learn OR control) AND (child OR children OR kid). The terms were combined and searched in abstracts. We carried out the same search queries in ACM, Springer, IEEE, Taylor&Francis, and Elsevier. Duplicate records, records unable to find full text, and records irrelevant to the topic of our research were removed, this resulted in 467 papers. We then conducted a more thorough manual elimination process to only select the papers that were most relevant. To be eligible for our analysis, the publications must present a novel design solution to digital autonomy and fulfill the following three criteria:

- Articles must be peer-reviewed full papers that were published over the last 10 years. Designing for children is a fast-changing area, however, we believe 10 years is a reasonable time span to reflect on both the more recent practices as well as the more established practices and their underlying design ideologies.
- Articles must be about supporting children's digital autonomy. Here we used Spear et al.'s definition for autonomy (see Section 2.1) as a working definition to filter qualifying articles. To be more specific, we were looking for papers around supporting children's autonomy (broadly around cognitive, behavioural, emotional) when interacting with digital technologies. The papers supporting children's autonomy in other fields *using digital technologies* were not included, e.g., healthy lifestyle, road safety, writing skills and etc.
- Articles must be engaged in a technical discussion about how the technological prototypes have been designed. We did not include any papers that were not specifically designed for children, without a discussion of a technical design/implementation, or with a more specific focus on supporting children with special needs.

[1] List retrieved from *Google Scholar Ranking* in April 2022.

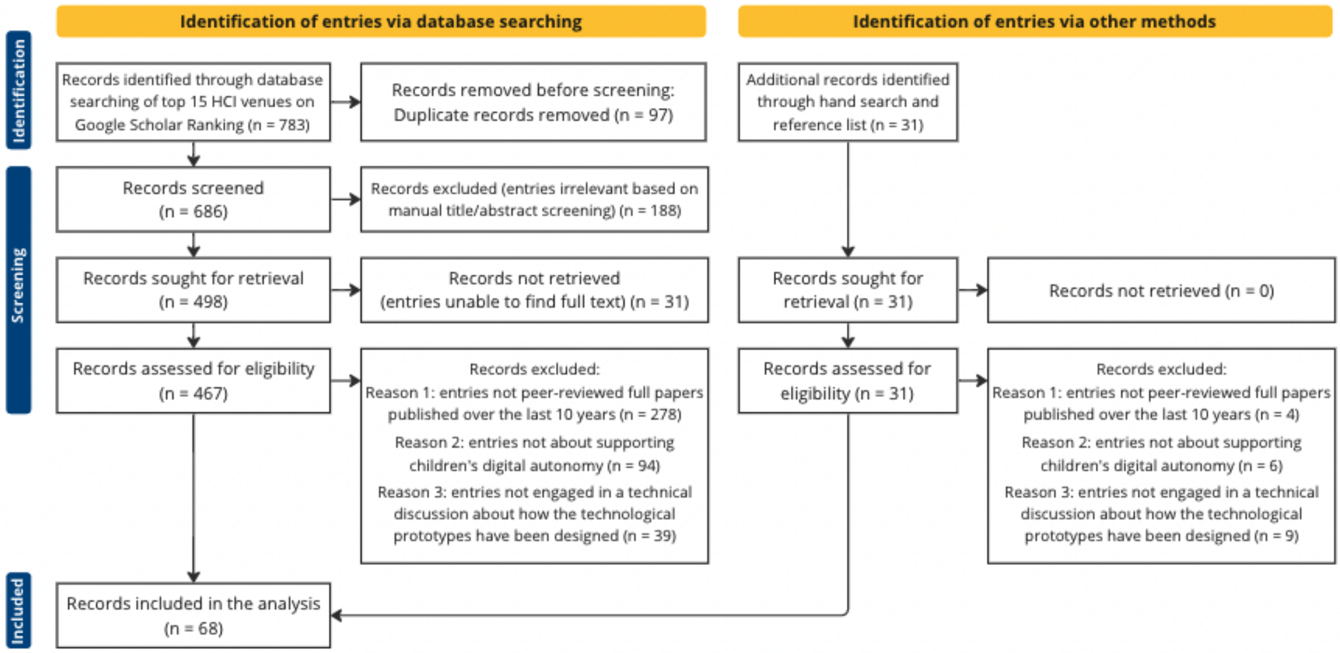

Figure 1: PRISMA flowchart of the article selection process.

The first author carried out the manual screening by skimming through the abstract of each of the papers. Out of the 467 papers assessed for eligibility, 278 of them were not peer-reviewed full papers published over the last 10 years; 94 of them were not specifically about children's autonomy in a digital setting but about scenarios such as healthy eating habits; and another 39 papers did not engage in a discussion on the design of a technological prototype. To control for inter-rater effects, the screening process was performed by both the first and second author. The inter-rater reliability was found to be good (Cohen's K = 0.78). Disagreements were resolved through discussion. The final dataset includes 68 papers, from which 12 papers were added following Wohlin guidelines for snowballing in systematic reviews [145]. Of the 68 papers, 47 are conference publications (all full-length proceeding papers), 21 are journal articles. The full list of articles can be found in Appendix.

3.2 Data Analysis

We then conducted an analysis on the final filtered set of papers, addressing our two research questions: R1). *How does the HCI literature conceptualise digital autonomy for children?* and R2). *What autonomy-supportive design mechanisms have been explored in apps and systems for children?*

Specifically, for R1, we applied a qualitative analysis process through an open-coding approach[78] by first looking for any existing definition or conceptualisation on the term "autonomy". If the paper does not specifically mentioned the term autonomy, we read through the whole paper to identify what goals or purpose they were trying to support in relation to helping children navigate the digital environment. During this process, we paid particular attention to their research questions, stated contributions, and sentences such as "the focus/goal of this paper is...". We identified a diverse set of positioning of autonomy or the goals towards autonomy, we then consolidated these into three groups of conceptualisation around digital autonomy. See Appendix for a complete codebook.

For R2, we aimed to identify the design mechanisms used for supporting children's digital autonomy. Similarly, we also applied a qualitative analysis process through an open-coding approach [78]. The analysis was conducted in a *bottom-up* manner [8]. For each paper in our database, we carefully read through all sections related to the actual design of their proposed technological prototypes together with diagrams of the design (if presented), and paid extra attention to descriptions around the incentives, motivation, theoretical and ethnographic groundings behind the design. In particular, for each technological prototype reviewed, we noted down the design details through which it tried to support autonomy (e.g., use of gaming elements, introducing peer collaboration elements, setting default goals for children). The prototypes with similar design details were then grouped into clusters, which were then compared and consolidated, based on the ways in which children's digital autonomy is meant to be supported (e.g., through providing external information input, through providing social context). This process led to a total of five high-level categories. See Tables 3 – 6 in Appendix for detailed illustration on the emerging and grouping of design mechanisms.

During the coding process, the first author and the second author independently coded 20% of the collected papers (15 papers), they then met to consolidate and *reconcile* codes into an initial common codebook, with a Cohen's kappa of 0.76. The first author then used that initial codebook to code for another 20% of the collected papers (15 papers). The first two authors reviewed the updated codebook and newly coded papers together to produce a new codebook that was used by the first author to code the rest of the papers. All co-authors were consulted to resolve ambiguous codes at this step to reach consensus on the final codebook.

4 RESULTS

In this section, we present the results of our landscape review of the existing conceptualisation of digital autonomy for children in HCI literature (R1), and our analysis on the design mechanisms employed to support children's digital autonomy (R2).

4.1 Conceptualisation of Digital Autonomy

Our analysis identified three groups of conceptualisations about digital autonomy from the existing HCI literature, namely: digital autonomy as *the ability to develop intrinsic motivation and self-regulation*, digital autonomy as *the ability to make critical thinking and informed decisions*, and digital autonomy as *computational thinking and literacy development.*

4.1.1 Digital Autonomy as the ability to develop intrinsic motivation and self-regulation. From about a third of the papers, we identified that digital autonomy has been positioned as developing children's intrinsic motivation and self-regulation. This conceptualisation was usually brought up and discussed in the context of supporting children's self-regulation on screen time [71, 72, 122, 150] and regulating their own online activities [2, 59, 83, 99, 119]. Through analysis of how autonomy was defined in these papers, we identified three specific focuses related to this type of digital autonomy, including *encouraging children's right to their own digital space*, *fostering intrinsic motivation*, and *developing self-regulation based on intrinsic motivation.*

Supporting *children's right to their own digital space* has been mainly discussed in the context of a child's right to privacy in relation to parental controls and negotiating the power dynamics between children and their parents, as highlighted by work from Ghosh et al. [59], Mcnally et al. [99], Ko et al. [83], as well as Sangal et al. [119]. These research highlighted the importance of children's *autonomy* against parental monitoring and restrictions, which often exercise excessive data surveillance of children's online activities without their consent or knowledge. As a result, these research explored mechanisms to encourage communication of privacy and respect between parents and children so as to support children's development of digital autonomy.

A step further is to support children to *internalise external rules and goals into self motivations*, often drawn from self-determination theory [71, 72, 122], to emphasise the importance of helping children to translate norms into intrinsic motivations. For example, in a paper by Hiniker et al. [72], autonomy is defined as *"for children to regulate their behaviours and develop intrinsic motivation"*, and a similar definition was also found in a paper by Shin et al. [122] – *"Supporting autonomy as triggering intrinsic motivation, which in turn helps people to internalize rules and show a change in behavior"*. This internalisation could be supported through making children aware of the consequence of their choices [38], encouraging meaningful discussions with their parents on relevant topics [83, 99], as well as supporting children to identify their own intrinsic interests and take ownership of constructing their own plans [72].

Finally, built on this internalisation, some research further emphasised the importance of *encouraging actual action development by fostering children's intrinsic motivation.* For instance, Hiniker et al. [71] explored supporting children self-regulating their screen time, defining autonomy as *"the ability to self-regulate: plan, set goals, and choose their own actions with intention"*. Similarly, Ko et al. [83] explored ways for children to self-manage their online activities, defining autonomy as *"the quality children need to develop into self-dependent adults"*, and *"the ability to self-regulate through making responsible choices"*. This aspect is different from the previous aspect by its emphasis on children's ability to take actions, driven by their intrinsic motivations. Efforts on supporting children to take actions include the use of notifications and alerts to remind children of their goals [71, 72], as well as encouraging children to self-monitor and self-reflect on their plans and goals from time to time [83, 119].

4.1.2 Digital Autonomy as the ability to make critical thinking and informed decisions. Another group of research, which although have not explicitly defined digital autonomy in most of the cases, addressed digital autonomy through their goals towards supporting children's ability to make critical thinking and informed decisions. This conceptualisation was usually brought up and discussed in the context of supporting children to interpret online information (e.g., adverts, stereotypical content) [11, 58, 76, 98, 109, 117], or to cope with more specific risks such as online privacy risks [3–5, 42, 85, 144, 149, 151], online harmful contents [9, 10, 67, 114], and cyberbullying [7, 113]. The goals of these research mainly focused on children's ability to *critically act on information* and *form self-identity.*

Research on supporting children to critically act on information emphasised on the importance of providing sufficient information for children, so that they can sense-make the current situation, be more aware of associated risks, and consequently self-reflect and take actions based on the information. In some papers, autonomy is defined as *"for a child to make their own informed decisions about what information to disclose online"* [85] or *"to make decisions and follow through at their own pace"* [4]. Some exemplar research include Parker et al. [109] proposed that children should be made more aware of how marketing information could be conveyed in online food adverts and investigated various ways to achieve this. Zhao et al. [151] developed a prototype which enables children to be made aware of the data tracking associated with their mobile apps and how their data could be transmitted to platforms and companies without them knowing. Rubegni et al. [117] supported children to be more aware of online gender stereotypes by encouraging them to self-reflect on their own possible choices when creating a digital story. And similarly, in a privacy game developed by Maqsood et al. [98], children were instructed to go through an everyday life of a game character Jo, and form judgement on what is the best decisions for Jo to make at various privacy decision points.

Apart from the line of work around supporting children to interpret online information and cope with online risks, there has been another interesting line of work around cultivating children's critical thinking around their self-representation online and thus form self identity. An example is Hou et al.'s work [76] on supporting children's online identity in international communities. Another paper [130] explored supporting children to be aware of their own emotional states when interacting with online content, thus reflect on their self identity online.

4.1.3 Digital Autonomy as computational thinking and literacy development. Digital autonomy was not explicitly defined in the third group of research in most cases. However, these papers presented ways to 'acquire the knowledge and understanding to evaluate thoughts and make decisions', i.e., the cognitive-level autonomy — through supporting children to develop an ability to *internalise the literacy and skill sets*, and to *make meaningful contributions*. This conceptualisation was usually brought up and discussed in the context of supporting children's literacy development such as computational thinking skills [21, 36, 37, 40, 116], coding skills [25, 39, 107], as well as various forms of digital literacy including algorithmic literacy [73, 95, 103, 153], data literacy [20, 146], AI literacy [43, 138] and etc.

To have the ability to *"internalise the knowledge gained"* [91] is positioned as crucial for children to develop computational thinking in a way that connects computer-based problems with their personal everyday scenarios as well as broader social issues and challenges, and then apply reasoning and actions upon them. Several papers explored how to support this internalisation process. For example, Rode et al. talked about enabling this internalisation process through problem-solving (e.g., *"generalizing and applying this problem solving process to other kind of problems"* [116]); Other papers also worked on encouraging children to relate new knowledge gained to their everyday life context (e.g., *"apply their new knowledge to everyday life context, including personally meaningful applications"* [15]), as well as to the deeper and larger context (e.g., *"Children were not only able to store and access data online, but they also get to explore larger and powerful ideas like privacy, scale, etc."* [36]). Related to this internalisation process, to *make meaningful participation* emphasised on children gaining the ability to voice and form their own opinions and conduct meaningful discussions based on literacy gained. For instance, Bowyer et al. [20] showed how children could develop voices towards civic data issues (related to their data autonomy) through a card game activity and discuss their concerns with their parents.

4.2 Autonomy Design Mechanisms

How has digital autonomy been supported? In this section we present an analysis of the 12 design mechanisms for supporting children's digital autonomy, clustered into 5 overall categories by their common mechanisms.

We started with providing an overview on how children and other adult stakeholders have been actively (or not) involved in the described autonomy mechanisms. For children's invovlment, we used Druin's widely adopted model (children as users, testers, informants, and full design partners [44]) to identify children's role in the design process. Out of the 68 papers (technological prototypes and designs) we reviewed, 13 did not involve children in the design process (only presenting their prototype designed for children, only have other adult stakeholders such as parents and teachers involved, or prototype design based on evidence gathered from literature review). 33 papers only involved children as *testers* for their prototypes, during which various types of field tests were conducted with the majority being empirical qualitative studies evaluating how children react to a certain prototype. Another 5 papers involved children as *informants* during the design, mainly through conducting interviews with children at various points of the design, to elicit their response or conduct brainstorming with them. Another 17 papers involved children as *design partners*, in which children were treated as equal design partners with adults in the design process. As for adult stakeholders, 3 papers involved teachers as co-design partners; and another 9 papers involved parents in the design process. It is worth noting that out of these 9 papers, all of them involved parents together with children (as parent-child pairs or family activities) and most of these studies were around supporting children's digital autonomy in terms of *develop intrinsic motivation and self-regulation*. See Table 7 in Appendix for details on how children and adult stakeholders were involved in the design.

4.2.1 Scaffolding. The first category of design mechanisms were synthesised based on their mutual standing on providing *external information inputs* for children to develop digital autonomy. More specifically, such external information inputs were typically provided in a scaffolding manner, which originates from Vygotsky's Zone of Proximal Development (ZPD) [143]. Vygotsky believed that when a student is in the zone of proximal development for a particular task, providing the appropriate assistance will give the student enough of a "boost" to achieve the task [143]. These design mechanisms provide children with support when they need it and helped them to move through their gaps of knowledge, see Figure 2 for a graphical representation and summary.

Just-in-time Prompt. Just-in-time prompts or 'pop-ups' have been brought into the prototype designs as means to give children "the support just when they need it" [70]. These designs provide an opportunity for children to conduct critical thinking and to make informed choices about the technology, typically through the use of 'help buttons' or 'information buttons'. For instance, *TalkBack* [109] developed a mechanism in which they present expert nutrition tips next to food ads online (e.g., displaying "Choose whole fruits rather than juice drinks with added sugar.") to promote children's critical thinking about food adverts. Similarly, in a prototype designed for supporting children navigating informational privacy online (*DOPA* [149]), a question is posed to children when they encounter targeted advertisements, prompting them to think about why this ads is generated for them, with the answer revealed at the following page, explaining how third-party tracking cookies work and thus help children interpret the targeted advert in front of them.

Informative Interaction. An important aspect of the ZPD theory is for learner to interact with and learn from a more knowledgeable other (with knowledge and skills beyond that of the learner) [143]. Designs in *informative interaction* mechanisms work by initiating children's interactions and communication with these knowledgeable others, such as from their parents [83], teachers [15], or the system itself [10] when they need help, so as to give them the information to prompt their critical thinking and informed decision making. For instance, Badillo-Urquiola et al. [10] designed a parent alert button and a "police popo" button, which children can click on and seek for advice when they encounter messages from strangers online; *We-Choose* [67] explored mechanisms that enable children

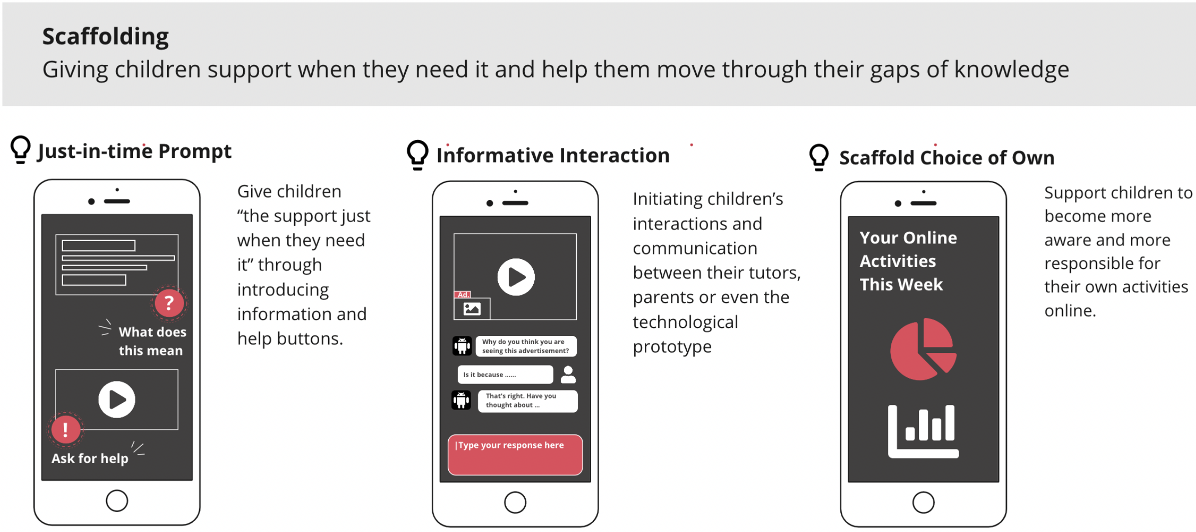

Figure 2: The autonomy mechanism *scaffolding* includes three design mechanisms: *just-in-time prompt, informative interaction* and *scaffold choice of own.*

to communicate and collaborate with their parents to set content filtering rules and establish what is appropriate. Meanwhile, designs were also implemented in ways to encourage children to ask questions or have conversations with the prototype itself, thus to scaffold them to navigate through online information [148].

Scaffold Choice of Own. The goal of ZPD is for children to move through their gaps of knowledge and be able to make their own decisions. Designs in this mechanism aim to support children to become more aware and more responsible for their own activities online. These designs are usually related to inspire children's intrinsic motivation and self-regulation. For instance, *Familync* [83] allowed children to self monitor their usage, thus to encourage their goals on limiting screen time and increasing study time. Similarly, another app called *Teen-alyse* [119] developed for children's self-regulation through showing them their app usage, together with a comparison of the rules set for children and whether they have exceeded that rule. Another design example was implemented in *MediaKids* [114], in which they explored the design idea of helping children to set up family media agreement with their parents, and encouraging them to follow through these rules by reminding them from time to time.

4.2.2 Decomposing. The second category of design mechanisms were synthesised based on their mutual standing on providing *fictional context* for children to develop digital autonomy. Thinking in abstract concepts could be difficult for children [124]. Decomposing provides a natural way of formalising tacit knowledge through breaking down and providing analogs — "a familiar scenario to think with" [1], which has a critical place to help children explicitly link their existing knowledge to the more abstract digital concepts. These autonomy mechanisms were designed to break down somewhat complicated concepts into entities that are more approachable for children, and provide analogies and metaphors that make concepts easier for children to process and to relate to themselves, advocating child-centred discovery learning, see Figure 3 for a graphical representation and summary.

Storytelling. Storytelling has long been known as effective ways for children to increase their comprehension skills [101]. Designs have been made to break down elements of digital concepts into stories by including relatable elements such as familiar characters. By exposing children to a range of digital scenarios, children were encouraged to develop agency and critical thinking for informed decision making, through relating these story scenes to their own experience. For instance, a series of comic-based stories were developed to support children to get familiar with internet safety scenarios [9]. Other designs also worked on supporting children to construct their own stories using digital elements. For example, in *StoryCoder* [40], children were introduced to the concept of loop by incorporating loppy music when creating their story. Kumar et al. [85] supported children to create their own stories around privacy decisions (e.g., the reader receives a suspicious email purportedly from a former classmate), while encouraging them incorporate decision points (e.g., whether the character in their story should click on the link inside the email) in their stories. Similarly, Hou et al. [76] invited children to create their own stories, with the focus to help them explore their online identity.

Gamification. Similar to storytelling, designs in gamification mechanisms work by breaking down digital concepts into game elements, and help children construct their knowledge as they interact with the games. We have observed different styles of implementation of gamification mechanisms: using gamification as a mechanism to *increase children's engagement*, or to *help children develop critical thinking as well as computational thinking skills* through asking children to follow a specific set of game rules. In terms of the former, Garcia et al. explored ways to incorporate gamification to motivate children (e.g., gain more star by finishing more exercises). On the other hand, most other gamification designs we observed fell into

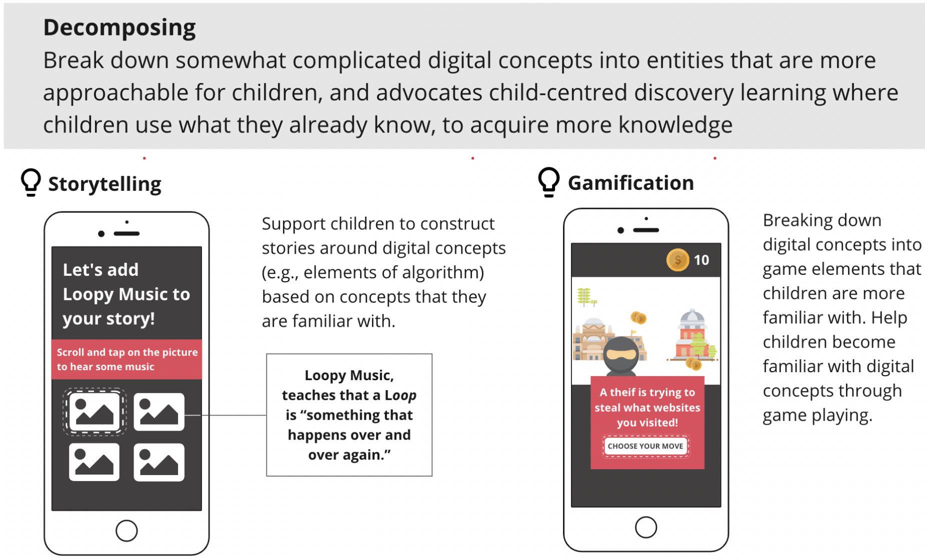

Figure 3: The autonomy mechanism *decomposing* includes two design mechanisms: *storytelling* and *gamification.*

the second category. For instance, Bowyer et al. [20] developed a card game that gamified data concepts, instructing children to play card games following rules which help them get familiar with how data were collected and processed [20]. Similarly, another data card game was developed by instructing children to put data cards into a black box, thus mimic machine learning processes [42]. Apart from card games, other games were developed to compare online privacy protection to protecting village against privacy thieves [144], or to instruct players to follow main characters through a series of events in their daily digital life and help them make smart decisions online [98].

4.2.3 Peer Support. Design mechanisms in this category typically originates from their mutual standing on providing *social context* for children to develop digital autonomy. Design mechanisms in this category encourage social interaction between children and their peers in order to promote their digital autonomy. Unlike scaffolding mechanisms, peer support mechanisms encourage children to turn to their peers instead of adults. Comparing with the traditional parent-child support model, peer support contribute to higher levels of active engagement for children [123], as well as improvements in skills, self-confidence and relationships [31], see Figure 4 for a graphical representation and summary.

Peer Collaboration. Enabling children's collaboration has been a long established topic. Through collaborating on tasks, reframing ideas, listening to each other and articulating their points, children will gain a more complete understanding as peers than they could as individuals [87], as designs supporting them to develop their critical thinking as well as computational thinking skills. *Catriod* [62] is a Lego-style programming environment which supports children to build their work on each other — "standing on the shoulders of their peers". Dasgupta [36] developed an online environment that encourages children to collaborate on coding projects. Other designs include setting up online forums that allow children to share their work [37], and online communities that allow children to work together, to collectively manage their privacy and security through posting and commenting as well as direct messaging one another [2].

Peer Comparison. The social cognitive theory suggests that human especially children learn new behaviour by modelling others' behaviours through observational learning processes whereas children learn new behaviours and strengthen their behaviour by observing the effect of others' behaviours and copy it through vicarious reinforcement processes [13]. Design examples typically work through encouraging children to compete with each other. For instance, in *TalkBack* [109], an app designed for cultivating critical thinking when interpreting online adverts, "friendly competition" is encouraged such that whoever wrote the most critical comments is awarded the Top Talker position to encourage engagement. Similarly, another design worked by building communities that allow children to compare their work with others, observe what others do and go back to improve their own work [62].

4.2.4 Digital Playground. Design mechanisms from this category were synthesised based on their mutual standing on providing *embodied context* for children to develop digital autonomy. These designs encourage children to freely interact with a digital system which is connected with a physical artefact, thus extending the playground to the physical environment around them (see Figure 5 for a graphical representation and summary). The goal of these designs is typically around developing children's computational thinking and digital literacy. For instance, Ofer et al. [107] explored the idea of a coding platform that controls a programmable hardware device for children's outdoor play, thus supporting children generate outdoor game ideas and implement them through coding

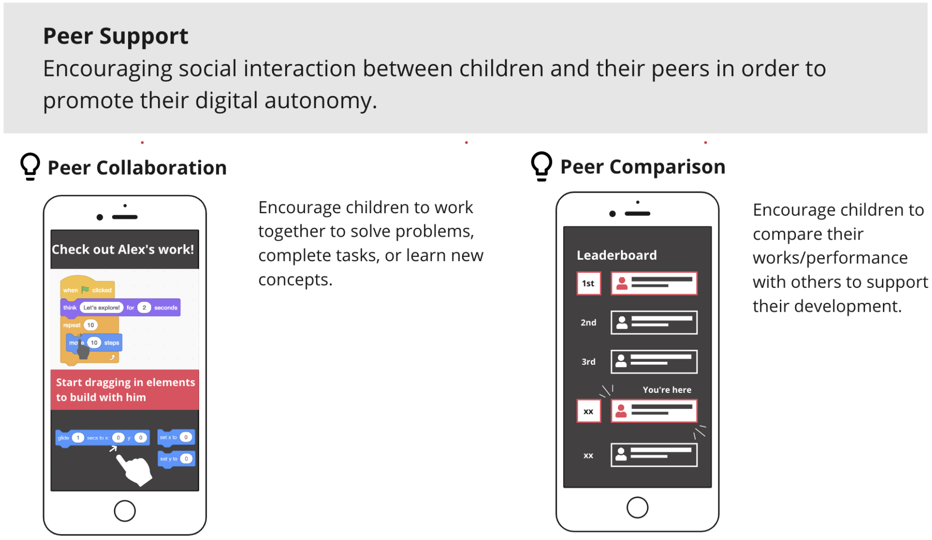

Figure 4: The autonomy mechanism *peer support* includes three design mechanisms: *peer collaboration* and *peer comparison*.

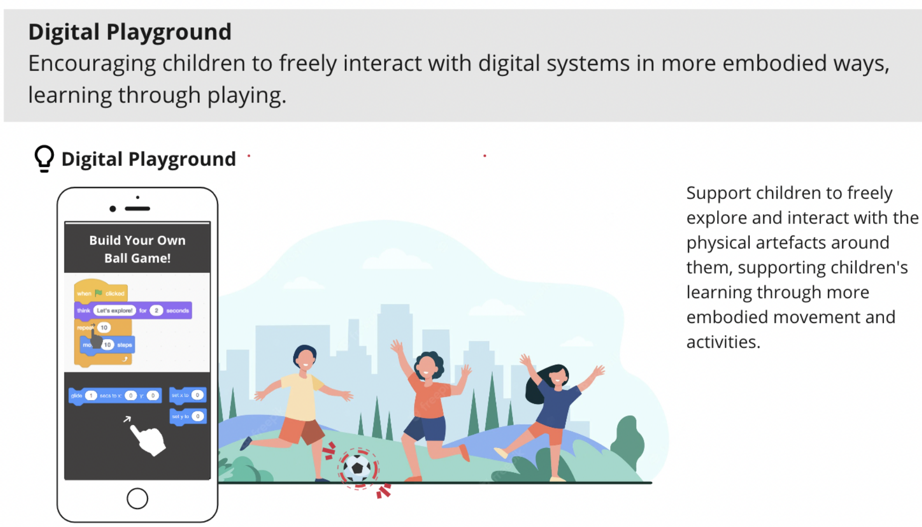

Figure 5: The autonomy mechanism *digital playground*.

activities. *DataMove* [21] is an interactive physical computing artefacts developed that enabled children to explore number systems and data through embodied movement and dance. Hitron et al. [73] worked on a platform on which children can train ML systems using a hand-held input device by performing different hand movements. Other designs include instructing children to make stuffed toys from pieces, connect them with electronics and then learn how to program it to be interactive [116]; and supporting children to imagine, code and display their programs on 3D surfaces [77]; as well as systems that made children's programming edits immediately reflected in the behavior of a physical device [25].

4.2.5 Nudging. A nudge is defined as "any aspect of the choice architecture that alters people's behavior in a predictable way without forbidding any option or significantly changing their economic incentive" [93]. These autonomy mechanisms were designed to impose subtle design changes that could alter children's behaviors and reinforce positive ones, and is closely related to the dual process theories [64]. See Figure 6 for a graphical representation and summary.

Default Options. Perhaps the most widely known type of nudging is default options, which is simply what happens if you do nothing. The power of the default has long been acknowledged to have a

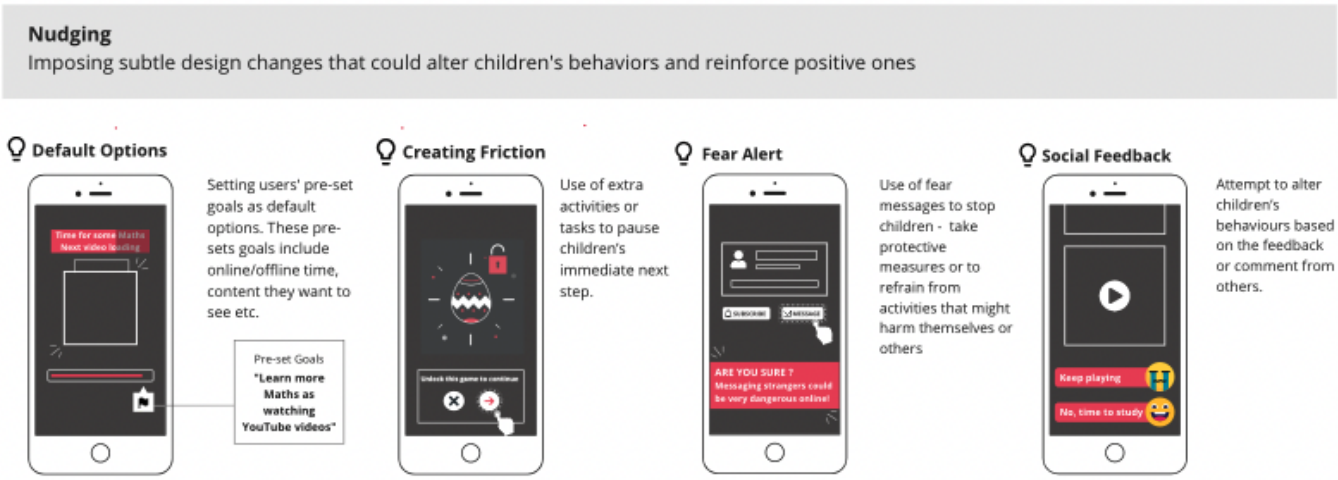

Figure 6: The autonomy mechanism *nudging* includes four design mechanisms: *default options, creating friction, fear alert* and *social feedback.*

significant impact on individuals' choices [60]. In our review, we found that default options were mainly realised through making users' pre-set goals (e.g., online/offline time, content they want to see such as educational resources) as their default options so as to support their self-regulation. For instance, in *Coco's Videos* [71], a video player designed for children to self-regulate their media use. It was found that lock-out mechanisms (no element of the screen was interactive, the user was locked out of the app once they reached this point) were more effective in terms of helping children to stick with their transition plan.

Creating Friction. Friction nudges attempt to minimize the intrusiveness and sense of restriction while maintaining the capacity to change children's behaviours. The typical design examples we observe from our review includes the use of extra activities or tasks to pause children's next step so as to help them enforce self-regulation or enable stop-and-think for critical thinking. For instance, *MABLE* [122] explored ways of introducing offline leisure activities (e.g., hide-and-seek games) for children to interrupt their continued screen activities. *Romi* [150] was introduced to children as a peripheral companion, such that children would need to interact with it before continuing their online activities. Gauthier et al. [58] explored a series of design features including the use of motion and colour, to initiate children's stop-and-think behaviours. Other designs include hiding some apps or content from children, making them harder to find [2].

Fear Alert. While friction nudges push children away from certain behaviours, remind nudges demand immediate attention and action from children. These designs make use of children's fear to stop them from doing harmful activities. For instance, Badillo-Urquiola et al. [10] explored a series of alert messages such as "Stranger danger alert!", "Reminder! It's not safe to share your location with people you don't know!", with the goal of nudging children to take protective measures or to refrain from activities that might harm themselves or others. Similarly, Dempsey et al. [38] explored a series of designs on warning messages with children related to the disclosure of their private information online.

Social Feedback. Social feedback nudges attempt to alter children's behaviours, typically for self-regulation, based on the feedback or comment from others. For instance, *Plan&Play* [72], a tool developed for supporting children's intentional media use, incorporated the design of a happy face of panda if children's current activity follows plan, and a sad panda face if their activity is off-plan. Other designs have also tried to display a privacy rating related to each options in order to alter children's choices online [5].

5 DISCUSSION

5.1 Conceptualisation of Digital Autonomy

One of the key goals of this research is to create a landscape understanding of digital autonomy for children in the HCI community. Our analysis identified some critical factors to be considered in addition to the popular Spear et al's definition [65, 90, 128] and some critical gaps in existing research.

While there is no consensus on what autonomy for children should look like [125], Spear et al's definition on personal autonomy, based on a conceptual analysis of extensive literature, has been widely accepted by existing research around self autonomy, and thus is considered as a great starting point for us to distill the more nuanced conceptualisation of digital autonomy in existing literature. We found that the majority of the research in HCI defined digital autonomy from the *self-regulation* perspective (see Section 4.1.1), emphasising the importance of *"supporting autonomy as triggering intrinsic motivation"* [122] and *"self-regulate through making responsible choices"* [83]. This aligns closely with Spear et al's definition of 'behaviour autonomy' - the ability to make decisions independently and follow through on these decisions with actions. Meanwhile, our analysis identifies that more than half of the articles we reviewed have explored digital autonomy through supporting children's *critical thinking* and *computational thinking* abilities (see Sections 4.1.2 and 4.1.3). Although many of these research have not provided an explicit definition of autonomy, they have identified supporting children's autonomy as their key goal and thus positioned their explorations within this context; in fact, their investigations align well with Spear et al's notion of 'cognitive autonomy' — the ability to acquire knowledge and understanding and to evaluate thought, voice opinions, and make decisions independently and to self-assess [14].

This review provides crucial inputs to the HCI community regarding the conceptualisation of children's digital autonomy. We show that in contrast to the general expectation that digital autonomy is largely about self-governance or behaviour change [26, 112], the ability of computational thinking and critically acting on these information is just as important. Indeed, research related to adolescence development has highlighted that the development of autonomy must be built upon a process of recognising, identity formation, to making independent choices (for example, independent of parental influences) [104, 111]. These previous research have described that the development of autonomy is influenced by multiple processes, including the cognitive processes of developing judgment and decision-making, negotiating social influences from peers or parent, as well as fostering healthy behaviour development [30]. Our conceptualisation analysis identified this focus on 'cognitive autonomy' support in the existing HCI research, although the conceptualisation of *cognitive autonomy* is probably less well-defined. By aligning existing HCI conceptualisations against the definitions from the other disciplines, we highlight the importance of considering the support of digital autonomy from a multi-dimensional aspect, which is essential to children's development process, and thus crucial for designing and building future digital autonomy support for children.

While our research provided a rich grounding for research around supporting children's digital autonomy in the behavioural and cognitive perspectives, our analysis also identified a critical gap in the existing HCI conceptualisation of digital autonomy - the support of children's development of *emotional* digital autonomy. Emotional autonomy refers to the ability to free oneself from emotional dependence [88], and is a vital part of the social-individual relationship development of children. Various previous research in child development and psychology has suggested the important role emotions served to help people address or overcome problems and attain their goals [56, 82]. Beyers et al. [16] pointed out the importance of emotional autonomy for children through clarifying its key difference to behavioural and cognitive autonomy under a case study, suggesting that emotional autonomy of children would correlate more with their intrinsic motivation. Meanwhile, the lack of support of such autonomy in existing HCI literature is perhaps not surprising, as under the existing conceptualisation, digital autonomy is more positioned as skill development (e.g., one's self regulation skills, critical thinking skills as well as computational thinking skills), leaving the social-emotional aspect of digital autonomy under-explored. We argue that children's emotional autonomy development should be much more greatly emphasised, and be considered more jointly with their cognitive and behavioural autonomy development. It would be challenging for children to partake in digital citizenship or develop deeper digital literacy without social-emotional skills [47], as these are the essential process by which children understand and regulate their emotions and behaviours, and make responsible decisions [53].

5.2 Connecting Autonomy Design Mechanisms to Digital Autonomy

How different autonomy mechanisms foster and support the development of children's digital autonomy then? We feel that this question is best answered by connecting our previously identified autonomy mechanisms to the groups of conceptualisation of digital autonomy. Of the 12 design mechanisms identified through our analysis, each design mechanism often managed to address multiple autonomy goals, and some design mechanisms are more focused on certain autonomy goals than other, as highlighted in Figure 7.

This many-to-many mapping between autonomy goals and current design mechanisms presents an informative picture of how currently digital autonomy has been supported. On one hand, it has been encouraging to see that each digital autonomy goal has been widely explored by various design mechanisms, which provides a rich input for our synthesis of design implications and best practices (see Section 5.3). On the other hand, our analysis also showed an unbalance and disjoint of effort around the explorations for supporting children's *self regulation* and *computational thinking* development: those designs that have been focusing on supporting *computational thinking* development have been much less likely applied to supporting children's *self regulation*, and vice versa. For example, we have found that *scaffolding* mechanisms have been often explored to support the development of children's self-regulation (e.g., the use of lightening/dimming flowers to promote children's self-regulation), and to encourage children's critical thinking (e.g., the 'help button' for gaining more information), but less often on computational thinking. Similarly *nudging* mechanisms have been mostly used to support children's intrinsic motivation and self-regulation (e.g., the use of default settings to nudge children to stick with their pre-set goals), but less often for critical thinking and computational thinking. At the same time, the mechanism of *peer support* and *digital playground* have been dominantly focused on supporting children's computational thinking, whereas *decomposing* mechanisms mainly focused on both critical thinking and computational thinking development.

This landscape analysis highlights some crucial directions for future explorations. To start with, the disjoint of designs for supporting different autonomy goals may indicate a need to *explore the role of these designs for achieving different autonomy goals.* For example, gamification has shown to be widely explored for supporting children's computational thinking development, through its decomposition of a complex concept. What kind of role could gamification play in supporting other autonomy goals, such as self-regulation? If gamification were combined with other design mechanisms for encouraging self-regulation, such as scaffolding or nudging, would it provide a more comprehensive, multi-faceted support for children's digital autonomy development? In fact, we have noticed that some research and design mechanisms have successfully attempted to achieve multiple autonomy goals, for example, *FamiLync* [83] has applied both informative interaction (*scaffolding*) and default options (*nudging*) in supporting children's self-regulation and critical thinking; and Hashish et al. [67] have explored just-in-prompt

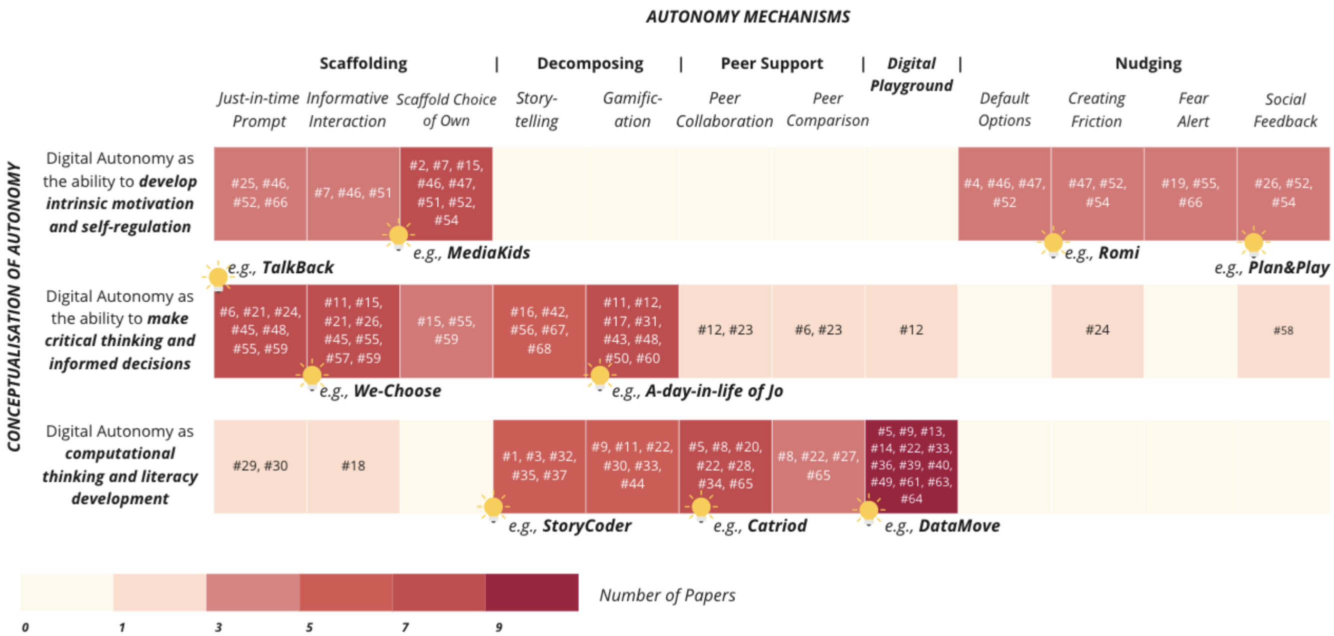

Figure 7: Crosstabulation between groups of conceptualisation of digital autonomy and the autonomy design mechanisms. #N represents paper number in Appendix.

(*scaffolding*) and gamification (*decomposing*) to support both critical thinking and computational thinking. By identifying this landscape of design mechanisms, we hope to provide designers and researchers a better starting point to explore new opportunities of supporting children's digital autonomy through the combination of multiple mechanisms or paradigms.

Our analysis also highlighted a clustering of different theoretical groundings underpinning the 12 design mechanisms, and the corresponding autonomy goals, which poses interesting directions for future theoretical explorations. As our landscape analysis shows, some design mechanisms have been more extensively explored for supporting children's *self-regulation* than others (such as nudging or scaffolding), whereas other mechanisms are more focused on supporting children's *critical and computational thinking* (such as decomposition, peer-support, or digital playground). The former group of mechanism are more often grounded upon self-regulation theories, such as Fogg's behavior model [52], Bandura's social cognitive theory of self-regulation [12], and the dual process theories of decision-making [48]. The latter group are often grounded upon theories related to different forms of knowledge construction, such as Piaget's theory on constructivism [18], Papert's constructionism theory [66], and cognitive learning theories [94]. Our analysis provides an initial observation of the relationship between different theories and the digital autonomy goals, and raises the question: whether there is an opportunity to explore and compare the different theoretically-guided approaches and examine how children's digital autonomy may be supported differently by approaches associated with a different theoretical grounding? Children go through drastic change in their developmental years. Although development research on children has been emphasising a holistic approach to their autonomy support, little has been understood in terms of the theoretical grounding related to supporting children's digital autonomy: the relationship and transition between children's knowledge acquisition, behaviour change and self-regulations in the context of digital autonomy has not been conclusively discussed [6, 32]. Such understandings would provide crucial inputs not only for future development of support for children's digital autonomy, but also the current attention on children's digital literacy development [86, 127] and its relationship with children's ability to cope with various online risks, datafication and associated autonomy building skills development [141, 151, 152].

5.3 Future Autonomy-Supportive Design Considerations

What should future designers consider when implementing and designing new types of autonomy mechanisms then? In order to provide more explicit support for future researchers and designers in their design quest for digital autonomy for children, we analysed the design considerations as well as the future directions and open challenges raised by the reviewed papers. We then consolidated these discussions and proposed five key design considerations for future researchers and designers (Table 1).

Identifying critical points of intervention can be of paramount importance. To start with, we recommend designers to consider identifying the critical points that could maximise influence. For instance, articles we reviewed have found that introducing *nudging* mechanisms at some critical interaction points (e.g., just when children finish a current task and are moving to the follow-up activity) could maximise children's behavioural change [28]; and varying

Design Considerations	*Examples*
Identifying critical points of intervention *(e.g. maximising impact or varying time of interventions)*	Hiniker et al. (#26) introduced a dialogue box "Return to Plan" when it is time to transition to next activity. Parker et al. (#6) displayed key questions such as "How is this ad trying to get your attention?" as children are ready to comment the online ads.
Promoting self-generated knowledge *(e.g. based on data that children can connect to or relate to their own experiences)*	Lee et al. (#44) instructed children to create their own game rules, help them transform their tacit knowledge about game play into formal computational logic. Soleimani et al. (#32) encouraged children to connect stories to real life scenarios and their personal interests.
Translating short-term boosts into longitudinal benefits *(e.g. exploring invoking deeper thinking or self-reflection)*	Alemany et al. (#19) first nudged children by displaying "The privacy risk of your post is HIGH", then introduced separate messages alongside the nudge, showing the exact users might see their posts, guiding children to think about what privacy means online.
Differentiation and Personalisation. *(e.g. taking more explicit consideration of children's age, developmental needs and cultural backgrounds)*	Horn et al. (#37) made use of children's existing cultural forms to develop stories helping them make sense of digital literacy concepts. Ko et al. (#46) studied how their app (supporting participatory parental mediation) was perceived differently by families with different parenting styles.
Low Floor, High Ceiling *(e.g. creating scaffolding, decomposing or nudging mechanisms catered for children's skills and ability, and permitting room for growth)*	Hitron et al. (#9) designed their system in a way to support learning experience that does not require any prior formal knowledge and allows immediate exploration. Flannery et al. (#35) designed their system to make if easy for children to get started on programming, then provide room for children to grow with concepts varying in complexity, but keep the tool manageable for the range of users.

Table 1: Future design considerations for more autonomy-supportive designs. #N represents paper number in Appendix.

the time of use of the *decomposing* mechanisms (e.g., gamificaiton) could optimise children's cognitive learning [22]. Meanwhile, we also recommend designers to explore varying the time of use of intervention. For instance, articles we reviewed have shown that supports coming from the *scaffolding* mechanisms would be best utilised if provided at a series of critical points along children's developmental stages. For instance, just-in-time-prompts were designed to provide support to children at various points, from just when they might encounter difficulties in finishing a task, to when they reflect on things learnt during the process [109], and informative interaction designs were usually embedded at points that could invoke children's critical thinking on an important topic [113].

Secondly, we propose that future designs should put more emphasis on *promoting self-generated knowledge* in children — enable children to think critically on issues instead of just habituate to the instructions/cues or being nudged without even realising it. The research we reviewed showed that it is critical for children to be able to explain and justify "why" they are doing things and "how" they formed their opinions, articulate their reasoning and elaborate and reflect upon their knowledge. Articles we reviewed have found that designs that provide children with the opportunity to generate knowledge based on their own experience would create stronger, and more long lasting autonomy for children, in comparison to learning based on information that is presented to children in a passive manner such as simply reading or listening to a source of information [74]. Based on these observations, we recommend designers introduce opportunities in guiding children to apply and transform their existing knowledge for new topics. For instance, in some *decomposing* mechanisms, children were encouraged to connect stories to real life scenarios and their personal interests [126]. Similarly, children were encouraged to create their own game rules during game play, and were then supported to transform their tacit knowledge about game play into formal computational logic [91].

Alongside promoting self-generated knowledge in children, it is also important to consider *translating short-term boosts into longitudinal benefits*. For instance, while some *nudging* mechanisms have been found to be effective to change children's short term behaviours, whether it could indeed initiate building towards positive habits is questionable [28]. Due to the nature of our reviewed papers (academic work based on short term empirical study), studies were only capable of capturing the short-term boosts, but had limited ability in measuring any long-term changes related to children's learning or behavioural change. We thus argue it is vital for future designers to take into considerations how to translate short-term boosts from autonomy designs into longitudinal benefits for children. Designer could apply *decomposing* mechanisms that nudge behavioural changes together with other mechanisms such as *decomposing* that invoke deeper thinking. Articles we reviewed showed that supporting children to self-reflect on their behaviours and choices in *decomposing* mechanisms could initiate their deeper thinking and longitudinal change in behaviour [117]; applying other design mechanisms together with *nudging* mechanisms has also been explored, and was found to be able to inspire children to think about deeper questions, which promotes their long-term behavioural change rather than just short-term effect [3].

Considering children's diverse needs and backgrounds — *differentiation and personalisation* is critical to the effectiveness of designs. For instance, many systems have tried to provide "personalised experience" for those explorations and learning experience. Here, "personalised experience" come in various ways. Such personalisation includes taking children's age, development needs, as well as cultural backgrounds into consideration. We recommend designers to pay attention the children's individual needs and take such into consideration. For instance, articles we reviewed have attempted to design stories based on children's age groups as well as distinct cultural background [75, 110]; and the use of *scaffolding* designs could work differently for children coming from families with different cultural background [83, 119], such as children living in more authoritarian family environment and more competitive educational environments could request more advanced level of scaffolding mechanisms.

Finally, an important aspect for a successful autonomy mechanism is to ensure the prototype allows a *low floor, high ceiling* for children. Here, "low floor" refers to an easy start that does not require any prior formal knowledge and allows immediate exploration; and a "high ceiling" enables more flexibility and provides room for children to grow and explore, especially for those children who were older or with more advanced ability [140]. More specifically, designers could consider applying *scaffolding* mechanisms in a more skill-appropriate manner, providing children with more instructions and scaffolds when they begin, and gradually supporting them to have more autonomy as they grow; *decomposing* such as storytelling could start with first supporting children to more easily comprehend a given story, then gradually support them to build their own stories; and similarly, *nudging* mechanisms could be first introduced for the very young children, who have yet developed skills and mindset to comprehend digital concepts, to nudge them towards better behaviours online without them having to go through the complicated digital concepts behind, then, as they developed more experience and demand for autonomy, other design mechanisms could be brought in to initiate the cognitive thinking, and to actively support children to engage, explore and demonstrate more of their digital autonomy.

6 LIMITATIONS AND FUTURE WORK

There are several important limitations of this work. We acknowledge that the implications of this work are limited by our search methodology that was primarily within the HCI literature, and we based on analysis on a literature review, which means that our sample of design mechanisms was focused disproportionately on research systems rather than commercial systems. We did this primarily out of practicality, as it is often difficult to get access to design documents for commercial systems especially across organisations, and our aim was to provide a first understanding of the current landscape of design efforts to support children's digital autonomy within HCI research.

One of the major challenges with designing for children is to make the design implications more translational to researchers and designers. By synthesising the framework of autonomy design mechanisms, we hope this framework, together with our proposed 5 key design considerations could provide crucial design implications around more autonomy-supportive designs for future developers and designers. Meanwhile, recognising the challenge of translating design considerations to concrete design practices, our future work involve actually working with developers and designers of children's technologies to get more direct inputs from them. We hope through actually involving developers, we could gain insights from developers on their concerns and challenges on how to adhere to the framework. Similarly, we hope to work more directly with children to get more direct input from them as the immediate next step, to find out how they comprehend the concept of digital autonomy, and how well these design mechanisms work for them.

7 CONCLUSION

Digital technologies have been increasingly integrated into children's everyday lives. However, what it means by supporting children's autonomy in the digital environment and how to achieve that remains an open question. Through a systematic review of the autonomy-supportive designs within HCI research, this paper makes three contributions to this area: first, a landscape overview of the existing conceptualisation of *Digital Autonomy* for children within the HCI community; second, a framework of 12 distinct design mechanisms for supporting children's digital autonomy, clustered into 5 categories by their common mechanisms; and finally, an identification of 5 critical design considerations for future development of supporting children's digital autonomy. Our findings provided a critical understanding of current support for children's digital autonomy in the current HCI research and identified critical factors and gaps to be considered for future more autonomy-supportive designs. We hope this research will provide a timely input in the HCI and child-computer interaction communities, and provide a foundation for future designers for children to reflect on what might it mean by designing to support children's autonomy.

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Theme	Code	Description / *Example Definition*
Digital Autonomy as the ***ability to develop intrinsic motivation and self-regulation***	Encouraging children's right to their own digital space	• Highlight the importance of children's autonomy against parental monitoring and restrictions
	Fostering intrinsic motivation	• *"for children to regulate their behaviours and develop intrinsic motivation"* • *"Supporting autonomy as triggering intrinsic motivation, which in turn helps people to internalize rules and show a change in behavior"*
	Developing self-regulation based on intrinsic motivation	• *"the ability to self-regulate: plan, set goals, and choose their own actions with intention"* • *"the quality children need to develop into self-dependent adults"*
Digital Autonomy as the ***ability to make critical thinking and informed decisions***	Critically act on information	• *"for a child to make their own informed decisions about what information to disclose online""* • *"To make decisions and follow through at their own pace"*
	Form self-identity	• Cultivate children's critical thinking around their self-representation online and thus form self identity
Digital Autonomy as ***computational thinking and literacy development***	Internalise the literacy and skill sets	• Connects computer-based problems with their personal everyday scenarios as well as broader social issues and challenge
	Make meaningful contributions	• Children gaining the ability to voice and form their own opinions and conduct meaningful discussions based on literacy gained

Table 2: Codebook for Conceptualisation of Digital Autonomy.

Emerging of Design Mechanisms			**Clustering of Design Mechanisms**	
Design Examples (*Technological Prototype* from #Paper)	Design Details through which autonomy is achieved	Design Mechanisms	How Autonomy is Developed	Category of Design Mechanisms
Outdoor Coding Platform [Paper#5]	Offer just-in-time prompt, instructions on coding activities	**Just-in-time Prompt**	External information input	**Scaffolding**
Chatbot [Paper#21]	Offer just-in-time prompt, support coping with online threats through chatbot instructions			
MindfulNest [Paper#25]	Offer just-in-time prompt, offer emotion regulation activities when children feel stress online			
Touchscreen Prompts [Paper#29]	Offer just-in-time prompt, offer in-app prompting techniques			
Stranger Danger [Paper#55]	Offer just-in-time prompt, show Police "Popo" button			
NUGU [Paper#59]	Offer just-in-time prompt, offer online safety tips			
We-Choose [Paper#11]	Support Informative Interaction, enable children to communicate and collaborate with their parents to set and establish what is appropriate	**Informative Interaction**	External information input	
Data Browser [Paper#18]	Support Informative Interaction on data literacy activities			
Cyberbullying [Paper#45]	Support Informative Interaction, support children seek for help			
FamiLync [Paper#46]	Support Informative Interaction, family dashboard to encourage family co-participation			
Stranger Danger [Paper#55]	Support Informative Interaction, parent-child communication button			
Cyberbullying [Paper#57]	Support Informative Interaction, parent-child communication button			
NUGU [Paper#59]	Support Informative Interaction, parent-child communication button			
Circle of Trust [Paper#2]	Scaffold choice of own, children can control and configure own screentime settings	**Scaffold Choice of Own**	External information input	
Online Safety App [Paper#7]	Scaffold choice of own, children can control and configure own screentime settings			
MediaKids [Paper#15]	Scaffold choice of own, children set up family media agreement with their parents, and encourage them to follow through these rules by reminding them from time to time			
Teen-alyse [Paper#51]	Scaffold choice of own, allow teen self-monitoring on app usage and flagged content			
Co-oPS [Paper#52]	Scaffold choice of own, allow self-monitoring			
Romi [Paper#54]	Scaffold choice of own, allow pre set goals			
Danger [Paper#55]	Scaffold choice of own, allow pre set goals			
NUGU [Paper#59]	Scaffold choice of own, allow pre set goals			

Table 3: Illustration on the emerging and clustering of design mechanisms (Scaffolding).

Emerging of Design Mechanisms → ***Clustering of Design Mechanisms***

Design Examples (*Technological Prototype* from #Paper)	Design Details through which autonomy is achieved	Design Mechanisms	How Autonomy is Developed	Category of Design Mechanisms
StoryCoder [Paper#1]	Use of storytelling elements, teach children computational concepts such as loop, variables as they make their own story	**Storytelling**	Provision of an fictional context for autonomy development	**Decomposing**
Fiabot [Paper#16]	Use of storytelling elements, raise awareness of stereotyping online			
CyberPLAYce [Paper#32]	Use of storytelling elements, icon and action cards help children to map out story ideas of their own			
ScratchJr [Paper#35]	Use of storytelling elements, children construct and play in sequences as multiscene stories			
Stickerbook [Paper#37]	Use of storytelling elements, children create their own story and learn about cultural forms online			
Phygital Book [Paper#42]	Use of storytelling elements, children learn about informational privacy through storybook			
ScriptKitty [Paper#56]	Use of storytelling elements, the Adventures of ScriptKitty focuses on the "so what" factor by letting students observe how easily security compromises can occur with commonly used free tools.			
Family Civic Data [Paper#3]	Use of game elements, data card games to invoke intergenerational conversation	**Gamification**	Provision of an fictional context for autonomy development	
ML Blackbox [Paper#9]	Use of game elements, instructing children to put data cards into a black box, mimic machine learning processes			
Electric Agents [Paper#12]	Use of game elements, help children make sense of media content through multiplayer game			
Digital Cultural Probe [Paper#17]	Use of game elements, set missions for children to raise awareness of online concepts			
ARCat [Paper#30]	Use of game elements, programming cards to learn about computational thinking			
Privacy Doodle Jump [Paper#31]	Use of game elements, expose children to a range of privacy consequences through game elements			
Mixed Reality Game [Paper#33]	Use of game elements, debug computational algorithms through mixed reality games			
Black Box Card Game [Paper#43]	Use of game elements, children were instructed to put data cards into a black box, leading to further discussion			
CTArcade [Paper#44]	Use of game elements, guide children move from concrete to abstract computational thinking			
Gamified Social network [Paper#48]	Use of game elements, allow children to complete tasks to collect points and badges to learn about privacy concepts			
A Day in the Life of Jos [Paper#50]	Use of game elements, a web-based game to increase children's digital literacy			
(Smart) Watch Out [Paper#60]	Use of game elements, encouraging privacy-protective behavior through interactive games			

Table 4: Illustration on the emerging and clustering of design mechanisms (Decomposing).

Emerging of Design Mechanisms → ***Clustering of Design Mechanisms*** →

Design Examples (*Technological Prototype* from #Paper)	Design Details through which autonomy is achieved	Design Mechanisms	How Autonomy is Developed	Category of Design Mechanisms
Outdoor Coding Platform [Paper#5]	Support peer collaboration, enhance children's play experiences by coding and playing their games together with their friends	**Peer Collaboration**	Social interactions and communications	**Peer Support**
Physical Programming [Paper#20]	Support peer collaboration, children could play together with physically connected beads and create codes			
Digital Communities [Paper#23]	Support peer collaboration, children work in teams to create stories, and introduce themselves to children in another country			
Collaborative[Paper#28]	Support peer collaboration, children could share data			
Problem-Solving [Paper#34]	Support peer collaboration, discuss and share their solutions			
ExposAR [Paper#65]	Support peer collaboration, discuss and share their solutions			
TalkBack [Paper#6]	Support peer comparison, such that whoever wrote the most critical comments is awarded the Top Talker position	**Peer Collaboration**	Social interactions and communications	
Scratch Community Blocks [Paper#8]	Support peer comparison, children could reflect on each others' projects			
DataMoves [Paper#22]	Support peer comparison, children could reflect on each others' dance moves			
Digital Library Communities [Paper#23]	Support peer comparison, children could reflect on each others' projects			
Catroid [Paper#27]	Support peer comparison, build on work of their peers			
ExposAR [Paper#65]	Support peer comparison, build on work of their peers			
Outdoor Coding Platform [Paper#5]	Support embodied learning, coding and playing their games together with their friends	**Digital Playground**	Embodied context	**Digital Playground**
ML Blackbox [Paper#9]	Support embodied learning, instructing children to put data cards into a black box, mimic machine learning processes			
Electric Agents [Paper#12]	Support embodied learning, help children make sense of media content through multiplayer game			
Pomelo [Paper#13]	Support learning through playing, free play with code blocks			
Computational Making [Paper#14]	Support learning through playing, free play with code blocks			
DataMoves [Paper#22]	Support embodied learning, children learn about computational thinking through dance moves			
Mixed Reality Game [Paper#33]	Support embodied learning, support children debug computational algorithms through mixed reality games			
Robo-Blocks [Paper#36]	Support embodied learning, tangible programming for algorithmic literacy			
Math Sphere [Paper#39]	Support embodied learning, an interactive sphere view window allow children to see and manipulate movements			
MakeCode [Paper#40]	Support embodied learning, physical computing			
Digital Toolkit [Paper#49]	Support embodied learning, teach children digital literacy through design-based learning			
A Walk on the Child Side [Paper#61]	Support embodied learning, teach children digital literacy through outdoor mobility activities			
Wearables for Learning [Paper#63]	Support embodied learning, smartwatch as a Tool for Situated Science Reflection			
Socio-Material Toolkit [Paper#64]	Support embodied learning, socio-material toolkit			

Table 5: Illustration on the emerging and clustering of design mechanisms (Peer Support, Digital Playground).

Emerging of Design Mechanisms → ***Clustering of Design Mechanisms*** →

Design Examples (*Technological Prototype* from #Paper)	Design Details through which autonomy is achieved	Design Mechanisms	How Autonomy is Developed	Category of Design Mechanisms
Coco's Videos [Paper#4]	Providing default options, lock-out mechanisms for children to self-regulate their media use	**Default Options**	Nudge behaviours	**Nudging**
FamiLync [Paper#46]	Providing default options, goal-based use limiting			
MABLE [Paper#47]	Providing default options, goal-based use limiting			
Co-oPS [Paper#52]	Providing default options, goal-based use limiting			
Stop&Think [Paper#24]	Create friction to nudge behaviour, introduce mechanisms to invoke stop and think in children	**Creating Friction**	Nudge behaviours	
MABLE [Paper#47]	Create friction to nudge behaviour, explored ways of introducing offline leisure activities (e.g., hide-and-seek games) for children to interrupt their continued screen activities.			
Co-oPS [Paper#52]	Create friction to nudge behaviour, app hiding			
Romi [Paper#54]	Create friction to nudge behaviour, a peripheral companion children would need to interact with it before continuing their online activities			
Soft-paternalism [Paper#19]	Nudge through alert messages, show children messages such as "the privacy risk is HIGH. The following users may see your post!"	**Fear Alert**	Nudge behaviours	
Stranger Danger [Paper#55]	Nudge through alert messages, show children a series of alert messages			
Privacy Warning [Paper#66]	Nudge through alert messages, let children design a series of privacy warnings			
Plan&Play [Paper#26]	Nudge through social feedback, display a happy/sad panda face as children make choices	**Social Feedback**	Nudge behaviours	
Co-oPS [Paper#52]	Nudge through social feedback, community feed			
Romi [Paper#54]	Nudge through alert messages, show children a series of privacy ratings			
Data Sensitivity [Paper#58]	Nudge through alert messages, show children a series of privacy ratings			

Table 6: Illustration on the emerging and clustering of design mechanisms (Nudging).

Role of Children & Other Adult Stakeholders	Description	Reviewed Papers	Examples
Children as Tester	Children have limited input in the design process, but are allowed to interact with technology before its completion. Adult designers, upon observation, make changes to the technology before its final inception.	[#2, #5, #8, #9, #15, #17, #18, #19, #20, #24, #25, #28, #29, #30, #32, #34, #35, #36, #37, #38, #39, #40, #41, #42, #44, #46, #47, #48, #56, #58, #59, #60, #61]	Various type of field tests were run with children, during which both quantitative and qualitative data were collected. Quantitative: Typical examples include pre-established questionnaires or scales that reflect a quantifiable aspect of children's behaviours or understanding (e.g. likert scale, time taken to solve a given task, how many times children press a button, eye-tracking data). Qualitative: Interviews and surveys were conducted with children, during which their performance, especially those behavioural/cognitive changes related to their autonomy were evaluated through analysing the observation notes, audio and video recordings of these sessions.
Children as Informant	Children are no longer called on solely at the end of the process, but rather are involved in the design process at various points, when researchers feel they will be informative.	[#1, #3, #11, #22, #52]	Interviews were conducted with children at various point of the design. Typical examples include presenting children with a low-fidelity prototype, and then elicit their responses through brainstorming sessions with them.
Children as Design Partners	Children become equal team members and stakeholders with adults in the design of new technologies. A child design partner participates in the entire design process	[#4, #6, #7, #10, #12, #14, #16, #21, #23, #26, #31, #33, #43, #45, #50, #55, #57]	Almost all of these studies used the cooperative inquiry methodology and subsequent techniques (e.g. bags of stuff, big paper, mixing ideas, technology immersion) to involve children in the co-design sessions
Adult Stakeholder as Teachers	Teachers were involved in the design/evaluation process of the prototype	[#18, #35, #49]	All these studies involved teachers for the design and evaluation of prototypes/curriculums designed for improving children's computational literacy.
Adult Stakeholder as Parents	Parents were involved in the design/evaluation process of the prototype	[#3, #11, #17, #21, #46, #51, #52, #54, #55]	All these studies involved parents together with children (as parent-child pairs or family activities) and most of these studies were around supporting children's digital autonomy in terms of developing intrinsic motivation and self-regulation.

Table 7: How children and other adult stakeholders were involved in the described designs. #N represents paper number in Appendix.