Aligning technological and pedagogical considerations: Harnessing touch-technology to enhance opportunities for collaborative gameplay and reciprocal teaching in NZ early education

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A B S T R A C T

New Zealand early childhood education (ECE) aims to provide a mix of teacher and child-led learning. A non-prescriptive curriculum allows for broad and rich early years teaching and learning experiences, with teachers responsive to devising engaging activities to align with children's diverse interests. However, such spontaneity presents an on-going challenge for teachers. Using a combination of Action Research, elements of User-Centered and Participatory Design, and Scrum software development approaches, we conducted a multi-disciplinary study which leveraged joint contributions of software engineers and experts, including practitioners (teachers), users (children and teachers), and domain experts (in ECE curriculum and pedagogy, and early childhood psychology). Examination of teacher–child interactions with our software demonstrated that our game was engaging, promoted collaborative gameplay (by promoting mutual awareness, opportunities for information, and equitable control) and supported reciprocal teaching (by aligning children's interests with content knowledge). Finally, it opens new avenues for introducing research and pedagogy-informed interactive educational software in the NZ ECE domain.

1. Introduction

The New Zealand Ministry of Education’s Te Whāriki (curriculum) framework for early childhood education aims to provide a mix of teacher and child-led learning [1,2]. A non-prescriptive curriculum allows for broad and rich early years teaching and learning experiences, with teachers responsive to devising engaging activities that are aligned with children's diverse interests (e.g. dinosaurs, vehicles, robots, birds) with the related content knowledge (e.g. number, measurement, shape, alphabet). However, such spontaneity presents an on-going challenge for teachers. For example, in a teacher-led classroom setting, the teacher is driving the choice of activities and related learning processes for the entire class. Conversely, in a child-led learning environment such as that in NZ ECE, children are free to play individually or in groups and it is the teacher’s role to notice what activity the child is engaged in and create opportunities for learning in that activity. For example, if a group of children are playing with a board game such as Bingo (see Fig. 1) the teacher will join the group and will ask questions related to the game such as “what colour is that castle?” while also encouraging the completion of the activity.

Herein lies the challenge for the teachers, they must constantly recognize opportunities for learning within the scope of each child’s interest at a given time. The main aim of our study was to design and develop a software solution to address and resolve this challenge in the domain of early childhood education (ECE). The specific goals of our study were to better understand different aspects and challenges of the problem domain, design and develop an engaging software solution that would preserve the principles of reciprocal teaching and support collaborative gameplay among teachers and children as widely adopted and practiced in New Zealand.

A strong criticism of child–computer interaction software solutions is the inattention to studying them in real-life contexts [3] and to aligning technological and pedagogical considerations
Our study acknowledges these as imperative steps in designing not just usable, but useful, software solutions. To this end, we conducted a multi-disciplinary research and development study which leveraged from the joint participation and contributions of software engineering expert and workers (principal investigator/supervisor and students), practitioners (teachers), users (children and teachers), and domain experts (ECE expert and early childhood psychology expert) to achieve its goals. We employed a combination of Action research [6–8] as the overall research framework, elements of User-Centered (for evaluation by end-users) and Participatory Design (for collaborative design with inputs from teachers and education/psychology experts) [9,10] as the design frameworks, and Scrum software development [7,11] as the software development framework. Using Action Research, we collected initial requirements through observations of child–teacher interactions at an ECE center. We designed and developed the software solution in an iterative and incremental manner in close collaboration with the end-users and experts using the User-Centered Design and Participatory Design approaches and Scrum software development respectively. Finally, we evaluated the software in three phases and made a number of refinements in response to the results and analysis. In this paper, we present the design, implementation and results of our multi-disciplinary study along with implications for research and practice.

2. Related works

Our project combines aspects of three areas that have a strong influence in ECE today: curriculum and pedagogy, and early childhood socio-cognitive development, and more recently, child–computer interaction. In the following subsections, we discuss some of the previous work in each of these areas as they relate to our study.

2.1. Early childhood curriculum and pedagogy

ECE in New Zealand follows the principles of Ako [12–15]. Ako is perhaps best described by the whakataukī (traditional Māori proverb) [16].

‘Mā tōu rourou, mā tōku rourou ka ora ai te āti,’
‘Through your basket (contribution) and my basket (contribution) we can feed our people.’

This proverb captures the essence of Ako to mean both teaching and learning. It recognizes that both teachers and learners contribute, as partners on equal terms, to learning interactions, and acknowledges the importance of shared learning experiences in the creation of new knowledge and understanding [12].

The principles of Ako are manifested and practiced in a number of ways in the NZ ECE context. The most prominent of these include a non-prescriptive curriculum as a means to a broader and richer learning experience, reciprocal teaching as a two-way learning process, and collaborative gameplay as the stepping stone for shared learning experiences in groups.

Reciprocal teaching

Reciprocal teaching is an instructional approach developed by Palincsar and Brown in 1984 [17] that is described as a “dialogue between teachers and students for the purpose of jointly constructing the meaning of text”. It is designed to improve students’ reading comprehension by teaching four key reading strategies: summarizing the main content, formulating questions, clarifying ambiguities, and predicting what may come next.

Reciprocal teaching is known to allow teachers to guide students towards greater autonomy within their learning groups [18,19]. The three main components of reciprocal teaching therefore include the presence of guidance (from teacher), fostering of autonomy (in students), and collaborative learning (in groups).

An in-depth study into the use of reciprocal teaching for imparting mathematical education in New Zealand [19] recommends that teachers need to: align critical mathematical components within particular concepts; support variety of problem-solving approaches attempted by students; and support collaborative learning amongst students. Our software solution was aimed to assist teachers in practicing reciprocal teaching of numeracy through supporting these dimensions.

2.2. Early childhood psychological perspectives on collaboration

Collaborative activities are activities in which individuals coordinate their actions to attain a common goal [20]. A growing body of evidence suggests that children’s understanding and engagement in collaborative activities develop significantly across the first four years of life [21].

Within the first year of their lives, children demonstrate early forms of collaborative skills by coordinating their actions with their caregivers in simple and highly ritualistic collaborative social games such as ball toss. By 24 months of age, toddlers demonstrate an understanding of the shared nature of collaborative action [22] and are able to skillfully coordinate their own actions with that of a social partner in novel collaborative problem-solving tasks, such as helping someone retrieve a toy from a puzzle box [23]. Also, by the end of the second year of their lives, evidence has revealed marked increase in the extent to which toddlers successfully coordinate their actions during cooperative activities with same-aged peers [24–26]. Children’s abilities to collaborate continue develop throughout the pre-school years with significant improvements in the extent to which children are able to coordinate their actions with and be responsive to same-aged cooperative partner [27,24,28,29]. Indeed, the ability to engage in collaborative action has been shown to play a significant role in promoting a number of facets of children’s cognitive development [30], such as planning [31], problem-solving [32], and memory [33].

Although there is now significant research evidence demonstrating that children make remarkable strides in their ability to collaborate with peers across the first three years of life, research surrounding the role of collaboration in facilitating learning in early childhood is in its infancy. As such, our study extends our understanding of how touch-based tabletop software applications may support collaboration between preschoolers in an ECE context.
2.3. Child–computer interaction in education

With the burgeoning popularity of touch-based software devices and applications, a number of touch-based applications have been developed and/or researched for children in and outside the educational context.

Several of those have confirmed the natural and intuitive nature of touch-based interfaces [3,34,35]. People find touch-based technology interesting and engaging to use because of the novelty and natural interaction that they offer [3,34,36]. Critically, children have been shown to retain attention for longer when using multitouch surfaces [37].

Research in ubiquitous computing now calls for a shift in focus from a reactive view (e.g. supplementing the environment to reduce human effort) to a more proactive view by enabling humans to outperform their natural limitations, such as extending their ability to learn, solve complex problems, and generate innovative ideas [38]. One such approach suggested in the context of play-based learning is the design of small-scale physical–digital toolkits comprising of objects and tangibles offering new interactions through digital technology [38]. A focus on designing for specific activities within bounded contexts as opposed to addressing ambitious challenges is also recommended.

A number of touch-based tabletop applications have been developed to support children’s learning. One such application, Spel-Lit, was designed to support primary school students with different abilities through a non-competitive and non-time restricted game design [35].

A recent study focusing on collaborative gameplay [34] featured tasks that required each player to specialize in different areas in order to work together and achieve a common goal. Khaled et al. [34] found that collaboration between players was manifested through turn-taking and division of effort. It was suggested that the tabletop learning environment promoted collaboration because it tends to “draw” players together.

There is now growing evidence supporting the importance of computer supported collaborative learning [39,40]. Recent work into collaborative multi-touch technologies [36] outlined three mechanisms of collaboration as: enhanced opportunity for mutual awareness, availability of information, and equitable control. Yuill and Rogers [36] bring together psychological and HCI perspectives on collaboration around touch-surfaces. Their work, and others, has provided support for the important role of collaborative learning in supporting cognitive development in ECE contexts [41,36].

Importantly, recent research supports a strong link between use of touch medium and children’s motivation to learn and collaborate [34,19]. Although a solid number of touch-based applications have explored literacy for children in an educational context [42,35,43], few studies have focused on the numeracy development. Our research addresses this gap.

3. Research and development

Our project was both evolutionary as it involved discovering the needs of the practitioners and users as we developed the system, and participatory as we needed to work in close collaboration with practitioners and domain experts. Considering these aspects, we designed our research and development methodology as a combination of Action Research [6–8] as the overall research framework, elements of User-Centered (for evaluation by end-users) and Participatory Design (for collaborative design with inputs from teachers and education/psychology experts) [9,10,44] as the design frameworks, and Scrum [7,11] as the software development framework.

Action Research is an iterative research method and involves cycles of studying (diagnosing) and planning; taking action; evaluating and analyzing the action; and then reflecting on the results [6–8]. User-Centered Design (UCD) is a process which involves users in the course of design, normally during evaluations [10], for example with children. Participatory Design [45,10] is a subset which allows for the involvement of more than one category of individuals in the design process, for example involvement of teachers as well as education and psychology experts in our case. Scrum [7,11] is a light-weight software development method that enables the iterative design and development of software in close collaboration with stakeholders [45,11].

We describe our application of these procedures in the following sub-sections. Note that, the steps of action planning, action taking, evaluating, and reflecting were performed iteratively such that feedback from the previous cycle fed into the planning of the next one. The same is true for the software development using Scrum. Doing so resulted in repeated refinement of the software solution.

3.1. Diagnosing the ECE domain

Using Action Research, our first step was to perform the diagnosis of the ECE domain in order to understand its key aspects and problems. In this step, we conducted the preliminary literature review in the area of early childhood education in the NZ context, and the use of digital technology in the field of education globally. Information captured from the literature review (summarized in Section 2) was strongly supplemented by observations and consultations with local ECE teachers. The software engineering expert and workers conducted initial observation sessions at a local ECE center catering to 3–5 year olds for 2–3 h a day for a week. As a result of the diagnosis step, we captured several critical aspects and key challenges of ECE in the NZ context:

- almost all numeracy and literacy skills were learnt directly through teacher interaction whilst children played various games indoors and outdoors (learning through gameplay), mirroring the New Zealand ECE learning style [2];
- a look at the types of activities children performed on a regular basis revealed that many of their interactions were through collaborative games. In particular, board games (e.g., Bingo) were a popular medium that enabled collaborative gameplay among children;
- the ECE center had already felt the impact of touch technology on the children at their center. The popular touch game Angry Birds had been played by many of the children at home. Children enjoyed role-playing the characters from the game at the center;
- teachers were responsive to spontaneously devising engaging activities that aligned children’s interest with content knowledge. An example of this was the teachers devising activities to impart learning about different birds and emotions around the Angry Birds game characters which the children had become extremely interested in at home.

Our most critical discovery resulting from the diagnosing step was that such spontaneity presented a critical on-going challenge for teachers.

3.2. Action planning

This step of the Action Research method involves planning the actions that needed to be carried out to resolve the problem [6–8].

Curriculum and pedagogical considerations

Discussions with teachers and further literature reviews led the discovery of the principles of Ako and its application in ECE
The principles of Ako suggest that teachers should acknowledge children’s interests and device activities around their interests while aligning them with content knowledge [12,14]. As a result of our initial observations of children playing at the center, and in discussion with teachers, we found that common topics of interests (or themes) amongst children were: animals, food items, cartoon or game characters (such as Angry Birds), buildings, transportation, etc. Further discussions with teachers led to selecting three themes to base our game around, these were: animals (birds, sheep, cats, whales, etc.); food (fruit, vegetables, cooked/uncooked food, etc.); and city structures (such as buildings, bridges etc.).

We also needed to align the themes with three content knowledge areas. The New Zealand Ministry of Education’s curriculum defines the main content knowledge areas within mathematics as important for the development of numeracy [46]. In consultation with teachers, we decided to focus the underlying content knowledge making up the question–answer sets on three specific areas of numeracy: number, measurement, and shape [46,14].

### Psychological and cognitive considerations

A growing body of evidence suggests that children are able to skillfully coordinate their actions with a same-aged peer by the time they are 3 years of age [27,25] and that engagement in collaborative activities supports several aspects of children’s cognitive functioning [30]. We capitalized on this existing evidence to develop our software game with a special focus on fostering collaborative opportunities.

### Child–computer interaction considerations

Prior to implementation, a couple of critical technological decisions had to be made. One was the selection of the tabletop hardware and the other was the choice software framework for development. We chose Microsoft PixelSense (previously called Surface 2.0) as the tabletop hardware solution due to its large screen space (40 inches) for supporting collaboration, high resolution display and support for tagged objects (tangibles). Tangibles add to the richness of interaction opportunities [47] and carry great potential for encouraging collaboration among children [43]. The choice of software framework was simplified with the selection of Microsoft PixelSense tabletop as it came with its own Software Development Kit (SDK), which features a touch emulator for designing and testing software. We also utilized Microsoft’s.Net XNA framework, which is designed to work with the PixelSense SDK and provides enhanced abilities to insert animated media.

Bearing in mind all these considerations, we planned to implement an engaging touch-based software game that would help align children’s interests with content knowledge.

#### 3.3. Action taking, evaluation, and refinements

The next steps involved iterative action taking and evaluation of the software, which were followed by refinements. Action taking involved the actual implementation of the software application using Scrum software development method. Evaluation was conducted via functional testing, teacher–trials, and children–teacher trials. Each of these evaluation phases were followed by refinements to the software. We describe these aspects in the following two sections.

### 4. Design and implementation

#### 4.1. Interface and interaction design

Considerable time was invested in learning about effective Natural User Interface design. Several aspects need to be especially accounted for when designing for Child–Computer Interaction (CCI). For example, when laying out touch surfaces, the recommendation minimum size for touch items is at least 15 mm squared with 5 mm spacing [48]. For multi-user touch environments, it is further recommended to avoid one user’s actions shifting the view of another user [48]. Furthermore, only gestures such as directly grabbing and shifting an object are considered natural and it is recommended that affordances be placed with the Natural User Interface to hint at gestures beyond the simplest ones [48]. The aforementioned aspects are particularly important for child–computer interaction where children are 3–5 year old with lower coordination and cognitive skills than the population average.

Another important aspect to consider when designing for child–computer interaction is to reduce cognitive friction. Cognitive friction is defined as the difficulty a mind has in understanding an application or gesture, often due to switching from one interaction paradigm to another or due to inconsistent program behavior. Based on our observations of collaborative play at the ECE center, and keeping in mind the need to reduce cognitive friction, we designed the software game as a variant of Bingo. Bingo was a popular physical board-game being played at the center. It affords the types of direct, physical actions children naturally perform, important for decreasing cognitive friction caused by a new medium. We were careful to avoid having different modes in the software game as it is seen as a cause of cognitive friction when modeling software after physical board-games [48].

The physical game included the concept of a common image (question) on a dice that was posed to all players, and individual boards which contained different combination of images (answers) for each player such that not all player-boards had answers to every question. The question–answer sets in the physical game were based on pattern matching popular cartoon images (Fig. 1). Our first interface design was a digital replication of the physical game’s simple pattern-matching of images. However, it did not address the goal of aligning children’s interest themes with content knowledge. Based on the learning from the first implementation cycle, a key action taken (feature implemented) in the second cycle was the introduction of ‘themed content’. In order to implement this themed content feature, we invested substantial effort into developing questions and answers that drew images from the identified themes (animals, food, city) while basing their underlying content knowledge areas (number, measurement, and shape). A database was added to the backend implementation to hold the question–answer sets based on the themed content. Simple pattern matching images were completely replaced by the themed content. The final version of the gameplay screen is shown in Fig. 2 (left).

Another key action taken (feature implemented) in the final implementation cycle was the inclusion of a tangible object to enhance interaction. We wanted to preserve the tangible aspects of the physical game in our touch-based software game in our NUI as much as possible. We utilized PixelSense’s ability to respond to tangibles (tagged objects) to enhance this aspect of our game by including a dice to change the questions in the central (shared) area (Fig. 2 Right). We also used the dice to select play, stopping accidental starts. The inclusion of this tangible had a remarkably strong impact on the collaborative aspect of the game, as we later observed during children–teacher evaluations (described below).

### 5. Evaluations

#### Functional testing and informal feedback

Software engineering expert and workers (supervisor and students) performed the earliest testing phase to evaluate both internal quality and external functionalities. The testing was
primarily done to prepare the application for future usability evaluations with participants (teachers and children). A number of refinements were made to address the issues which arose during internal evaluations. For example, we discovered situations where the same question-images came up in the central area that did not have a matching answer-image in any of the four boards. We realized this was a result of random selection of question and answer-images from the database without ensuring a link between the two, which was promptly rectified.

Informal feedback from teachers was received, where they suggested we use child-friendly fonts (such as comics sans serif, instead of times-roman) in black color (instead of the current blue color) as a number of children may not recognize alphabets in serif fonts or may have difficulty due to color-blindness. Such fine details could only be captured through feedback from teachers. This led us to acknowledge the importance of initial functional testing and informal feedback from teachers as it led to a number of issues being fixed, which would have undoubtedly and gratuitously problematic for our users (children) during user evaluations.

Teacher trials and refinements

As a part of the Participatory Design approach, we invited teachers from the ECE center to provide feedback on design. Six teachers evaluated the software (in three groups of two) and provided valuable feedback.

As a result of the feedback from the teacher trials, we added a start menu prior to the gameplay screen so the children could select their desired themes (animals, food, city structures) upfront. The game would then load with appropriate content limited to the chosen themes. This was important in order to preserve the principles of Ako and allow children to be led by their natural interests.

We also considered the possibility that different children in a group may wish to play different themes, and this could give rise to potential conflict or feeling of dissatisfaction amongst those whose choice was not selected. Therefore, we enabled multiple theme selection, in an effort to ensure that all children felt as though they had some control in the direction of the game, which is important for supporting collaborative environments [48]. This is in alignment with the New Zealand Ministry of Education Te Whāriki (curriculum) framework's goal of contribution (Manu Tangata) [2].

We further implemented two difficulty levels (normal 3 × 3 grid answer boards, and challenge 4 × 4 grid) in response to teachers’ concerns regarding the shorter length of the game and the complexity of some questions being appropriate for younger children while other questions and a longer game being better suited to older children or those with more advanced knowledge. We replaced any remaining clip-art with real-life images as the teachers unanimously desired.

Children–teacher trials

In the final round of evaluations, as per the suggestions of our domain experts, we transported the PixelSense to the ECE center to let the children play with the new software game in their own familiar environment. We hosted evaluation sessions over 3 days, where a total of 15 children (aged 3–5 years) played with the software game in 5 different groups, each with a teacher. Table 1 provides a summary of the groups. We video recorded the sessions for analysis purposes.

Immediately following each of the children–teacher evaluation sessions, we requested the session teacher to ask their respective group of children a few questions to elicit some direct feedback from children. We then asked the teachers a set of questions individually to collect their response and feedback. Results and analysis of the data collected via evaluations, observations, and questions asked of children and teachers are presented in the next section.

6. Results and key findings

All evaluation sessions were conducted by two software engineering workers and at least one of the experts. Notes were taken during observations. Video recordings of the sessions were later analyzed in-depth by the three experts (software engineering, early childhood education, and psychology) separately first, and then discussed together. We used thematic analysis and open coding i.e. we specifically sought evidence of reciprocal teaching and collaboration, while remaining open to other emerging patterns.
All three experts found relatively strong evidence to support the main categories: Engagement, Collaborative Gameplay, Collaboration, Reciprocal Teaching, Content Knowledge, Control, Preserving Ako. Other categories (e.g., Gender and Control, Ethnicity) were not reported due to their preliminary nature.

The key findings that came forth after the expert analyses of the final children–teacher evaluations were related to: Engagement, Ako and Reciprocal Teaching, and Collaborative Gameplay. We describe each of these findings in the following subsections. Given the exploratory and evolutionary nature of our study the following results, while clearly supported within the context of this study, will need further validation through a longitudinal study.

6.1. Engagement

Engagement can be defined and discerned through attributes such as on-task behavior, focus, direction-following, enthusiasm, volunteering, and showing intensity [49]. There was ample evidence of engagement along these dimensions. Most children were completely taken by the table immediately upon entering the room. Attention was sustained generally well across the groups. Attention was not sustained most often when a question was too difficult (the measurement content seemed to be most difficult). When asked, most children wanted to play the game again—mostly right away. Teachers who were more active in asking questions, engaging the children to look at the display and find answers, promoted children’s sustained attention.

Immediately following an evaluation session, the participating children were asked a set of questions. A summary of the results for two of the questions which elicited the most response is presented in Fig. 3. These questions were:

- Q1: did you enjoy that game?
- Q2: would you like to play that again?

Both questions were focused on capturing engagement aspect of the game. Of those that responded, 92% agreed and 8% disagreed to Question 1; 88% agreed while 22% disagreed to Question 2. Other questions did not yield much response from the children. We discuss this aspect of ‘no responses’ (Fig. 3) further in the limitations section later.

6.2. Ako and reciprocal teaching

The game demonstrated several occurrences of the principles of Ako and reciprocal teaching in action, manifested as themed content to align children’s interests with content knowledge, fostering autonomy by valuing children’s opinions and choices, and encouraging collaborative learning (over competition). The presence of guidance from teacher was also evident in the observations.

Themed content

One of the main goals of our software design was to help teachers resolve the challenge of devising engaging activities to align children’s interests with content knowledge. As a result, we designed our software game to provide ‘themed content’ where the main screen of the game provided three themes for children to choose from: animals, food, and city structures (e.g., buildings, bridges, stairs). Each of these themes was aligned with a specific content knowledge area: numbers, measurement, and shapes respectively. We found the use of ‘themed content’ to be particularly effective, as the children were focused on the themes. For example, children would make comments similar to this: “I want to play the Animal game. Animal, animal.” when selecting a theme, rather than noticing the text “numbers” (content knowledge) which was meant to help teachers prepare for the content area of the game.

Another question asked to children was “What was your favorite part of the game?” Of those who responded, a majority mentioned “Animals” or named an animal (Cats, Kangaroo, Dolphin), one of them mentioned “Fruits” which were aspects of the themes. Only one of the children, particularly interested and advanced in number recognition, responded with “Numbers”, which was an aspect of the content knowledge. This reaffirmed the purpose behind design decision of ‘themed content’ as clearly capturing children’s attention and engagement via themes (animals, food) while aligning them with content knowledge.

Valuing children’s opinions and choices

Elements of reciprocal teaching were found across all groups in varying levels. In Group 1, the teacher started the play session by posing a series of questions to focus children’s thinking about choices. The game’s initial menu screen facilitated discussions around choices by providing the opportunity to select from the three different themes.

It was interesting to note that the teacher initially interpreted the choices as mutually exclusive, while the children attempted to select multiple options. Once the teacher realized it was possible to select multiple options, a collaborative decision was made, and respected by the teacher “you want to play both? Okay”. As the game began, the children and the teacher worked together to find solutions, displaying the concept of Ako in action. For example, the teacher used phrases and questions in response to the children’s answers to the posed questions.

Reciprocal teaching for numeracy in action

In their study on using reciprocal teaching in mathematics education, Quirk [19] notes a possible barrier to solving word-problems in mathematics being the students’ limited ability to read or comprehend the text. This potential problem was mostly inconsequential in our study since the students being between 3 and 5 year olds, were not expected to read the questions out themselves. The teachers tended to read the questions out to the groups as well as encouraged questioning and discussion to help the students comprehend the question from multiple perspectives. An example of numeracy-based reciprocal teaching was seen when an image of three ducklings appeared in the central question area (see Fig. 4):

Teacher (reading question): “how many feet do these ducklings have?”
Availability of information

We also noted that the presence of information helped support the emergence of collaboration amongst the children, as predicted by Yuill and Rogers [36]. Children developed an understanding of the rules of the game through explicit information and guidance provided by teachers, which supported more frequent collaboration. This was most evident in Group 1 where the teacher informed children of the intent of the game after she had spent some time exploring it herself along with the kids. Once information was made available to the children, they collaborated more.

The need for availability of information was emphatically felt when during the first session, participants of Group 1 (both teachers and children) repeatedly verbalized the need to “see what’s underneath the smiley” in situations where children had accidentally touched a correct answer and it became consequently obscured by a smiley face (used to indicate a correct response). In later sessions, once the software had been refined to implement the ‘uncover correct answer’ feature, the children liberally used the feature to double-check their answers and show their correct response to the teacher and peers, which clearly enhanced collaboration (Fig. 5). The availability of information – uncovering a correct answer in this case – became a key contributor to collaborative learning in the groups.

Control

The use of the dice (tangible tagged object) became a physical manifestation of shared-control in the game. It was necessary to use the dice to change the question. In absence of any time-constraint, the use of the dice controlled both the flow and pace of the game. We found several instances (repeated across groups) where the both teacher and children shared the dice and hence control of the game. Most teachers tried to teach turn-taking – by letting children take turns using the dice as a mechanism to change the question – which seemed to foster more collaboration between teachers and children on the one hand and amongst children on the other. The decision to advance the game by changing a question progressively became a collaborative and collective activity marked by verbalized discussions and verbal/physical consent (e.g., children nodding).

Collaboration over competition

As per recommendations and feedback from the teachers, we underplayed any competitive aspects of the game by avoiding a scoring system (implicit or explicit). We also cautiously underplayed any aspects of ‘winning’ by adding a gentle ‘zap’ sound whenever a row of correct answers (horizontal/vertical/diagonal) was achieved on a board and covering that row with a faded blue color to indicate its complete state.

During evaluations and analysis, we found that while some children were intrigued by the sound, none of the children seemed to associate it with an aspect of ‘winning’ the game and would continue on with the game regardless.

The participation of the teachers in the design sequences ensured that the gameplay was kept intentionally flexible so the group (teachers and students) could decide to quit at any time or keep playing until all players had finished their individual boards. In practice, we found that in all cases, when some children had finished identifying all the answers on their own board, they naturally – or upon encouragement from teacher – went on to help others finish. For example, older children, having finished their own boards, were gently encouraged by the teacher to help out the younger child (Fig. 6). The software design of our game helped fulfill the New Zealand Ministry of Education Te Whāriki (curriculum) framework’s goal of contribution (Mana Tangata) defined as children being provided equitable opportunities for
learning and being encouraged to learn with and alongside others [14].

Finally, we had asked teachers to rate the statement “Children Collaborated with each other to find the answers” on a Likert scale of 1–5, where 1 indicated strongly disagree and 5 indicated strongly agree. Summary of the responses is presented in Fig. 7. The average teacher rating for collaborative aspect of the game was 3.8 which supplemented the findings from the expert analyses.

7. Discussion

Here we discuss some interesting implications of our study and findings as they apply to the areas of early childhood education, early cognition and psychology, and child–computer interaction.

7.1. Implications for education

There was ample evidence of children’s awareness and discussion of the content knowledge areas in the game (numbers, measurements, shapes) suggesting that the game presented concrete opportunities for children to build and consolidate numeracy concepts.

Children’s number knowledge was evident in a range of examples and shows a variety of mathematics concepts. For example, when the teacher reads the question “How many eyes does an owl have?” child answered “two” or when a child related a number to their everyday knowledge and observations “seven, there is a seven at my house” this evidence of quantification shows the child’s number knowledge [50,51,14].

With shape identification: children matched the Christmas tree with the term “triangle”. This geometrical understanding shows some children’s “skill in using the counting system and mathematical symbols an concepts, such as numbers...shape and pattern, for meaningful...purposes” [2]. Interestingly, children could not make comparisons using the “arc” of the rainbow as this is not a commonly used term with young children.

Measurement knowledge was observed in Group 4 in which P12 quickly identified short, long, heavy, bigger, smaller, full, empty and thus, displayed numeracy skills [2]. While the physical bingo board game was based around pattern matching, our software game featured themed content which provided ample opportunities to discuss concrete numeracy concepts.

7.2. Implications for cognition

Interestingly, we did not see many differences emerge between the 3- and 4-year-olds in their collaborative abilities. Some 3-year-olds performed well on the task and some 4-year-olds experienced some difficulties. One reason for the lack of age differences might stems from previous work demonstrating that children are skilled collaborators with peers by the age of three [21]. Other factors that might be important for children’s tendencies to collaborate with others on this task might be their language, cognitive ability, and/or personality. Although we did not attain a measure of children’s
cognitive and language competence, comments provided by the teachers led us to believe that children with English as a second language had more difficulties collaborating with others on this task. Perhaps future research in which we create groups of mixed-age and mixed-abilities will demonstrate the nature of the relationship between age and ability on this task.

7.3. Implications for child–computer interaction

We concur with Crook [4] that researchers and experts in CCI may not – and often do not – have relevant academic grounding in educational pedagogy and developmental psychology. It is not surprising therefore that CCI software solutions are strongly criticized for their inattention to aligning technological, pedagogical and psychological considerations when designing software for children. We address this significant issue by initiating a collaborative research and development approach which involves contributions from software engineering expert and engineers, user groups (children and teachers), and domain experts (pedagogy and curriculum, and psychology experts).

Competitive contexts are defined as those where if one person accomplishes their goal the other cannot achieve theirs while cooperative contexts are those where one person’s accomplishment of their goals is dependent on everyone achieving theirs [52,53]. In line with these definitions, our game strongly supported a cooperative context where the progress of the game was dependent on all children answering their respective boards as enabled by the social context of the game and teachers as they encouraged New Zealand Ministry of Education Te Whāriki (curriculum) framework’s goal of contribution (Mana Tangata).

An important finding of our study supports the claim that User-centered and participatory design approaches [9,10] which is what we adopted a multi-disciplinary team

Another remarkable finding with regards to collaboration was that collaboration seemed to be enhanced by children’s spatial location; children standing beside each other on the same side of the table seemed to naturally collaborate more. However, children on opposite sides of the table seemed to either compete when left to themselves or only collaborate periodically when the teacher explicitly fostered division of work (e.g., dividing tasks of counting and number recognition).

The design and layout of the game seemed to contribute to this effect where individual boards along the long edges of the table faced outwards so that children on the same side could easily see and read each other’s boards but could not effortlessly see the boards (answer images) facing the opposite side. When explicitly guided by the teacher, children would walk over to the other side to help another child (usually with lower cognitive ability, as with P5 helping P8, Group 2).

However, this may also have been influenced by children’s choice of where to stand initially in response to whether they were playing with their friends or with other children of the center who they normally did not interact with much; children may have chosen to stand beside their friends and as a result collaborated more with them.

Due to their close interactions with children on a regular basis, ECE teachers usually have a good grasp of children’s preferences and friends. Most teachers could recall names and exact ages of all children in their groups during evaluations. We further probed this pattern by asking the teachers to categorize the children in different groups as: best friends, good friends, casual playmates, and hardly-ever-interact. To our surprise, the manager (also a teacher) responded: “in all the groups I would have to put them in the ‘hardly ever interact’ category. The exception would be [P5] and [P6] in Group 2 who have been ‘casual playmates’, but the relationship is developing into one of ‘good friends’.”

This information has strong implications for our study. In particular, it strengthens evidence in favor of the ability of our game to foster collaboration and teamwork amongst children, most of who hardly interacted with each other. It also strengthens the evidence in favor of ‘same-side-collaboration’ pattern where children on the same side naturally collaborated more. An exemplar of this pattern were two girls who displayed a high level of collaboration and teamwork, building over the course of the game, to the extent they came across as ‘best friends’ to the research team during analysis of the video recordings. Future work can look to explore this concept further.

7.4. Recommendations for research and practice

Based on our positive experiences in this research we now discuss some concrete recommendations for research and practice for other designers, developers, and researchers working to create similar educational software. These include:

- A multi-disciplinary team: we adopted a multi-disciplinary team approach to this research project by including education and psychology researchers in addition to software engineering/HCI experts. It not only helped us understand the problem domain from multiple perspectives, but also proved to be very effective in informing the software design as we were able to consider and include curriculum, cognitive, and CCI perspectives. We strongly recommend taking a multi-disciplinary approach to design and develop educational software for children.

- User-centered and participatory design approaches: including teachers in the design stages allowed us to incorporate educational concerns and elements which would have been otherwise difficult to capture at best or were in direct contrast to our training as software engineers at worst. For example, as software developers of a game we were initially inclined to include a scoring and explicit game win/lose concept. However, the teachers clearly informed us that the Te Whāriki (curriculum) framework strongly supports collaboration and inclusion over competition. As a result, we avoided any scoring and purposefully underplayed any aspects of ‘winning’ (i.e. child completing all tiles). Such insight was brought purely as a result of adopting elements of user-centered and participatory design approaches [9,10] which is what we recommend adopting by including teachers and children in the design process.
Table 2
Aligning pedagogical and technological considerations.

<table>
<thead>
<tr>
<th>Pedagogical considerations (NZ ECE and collaborative learning guidelines)</th>
<th>Technological considerations (design criteria introduced)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Children’s interest-led learning</td>
<td>Themed content.</td>
</tr>
<tr>
<td>Valuing children’s opinions and choices</td>
<td>Dynamically generated content based on multiple theme selection.</td>
</tr>
<tr>
<td>Mutual awareness</td>
<td>Orientation of content to enable peer-content visibility.</td>
</tr>
<tr>
<td>Availability of information</td>
<td>‘Uncover correct answers’ feature to enable information availability and re-visiting.</td>
</tr>
<tr>
<td>Shared control</td>
<td>Use of tangibles (as dice).</td>
</tr>
<tr>
<td>Collaboration over competition</td>
<td>Designed to exclude scoring and to support all players completing their turns.</td>
</tr>
</tbody>
</table>

- **Experiencing the application domain**: in addition to the knowledge and expertise provided by the education and psychology experts and teachers from the ECE center, we made personal efforts to better understand the application domain and context. As software engineers and HCI researchers, our understanding of the domain (such as education) is typically limited to our reading of relevant literature. Using Action Research, we first went about diagnosing the domain and spent time observing children and teachers in their natural setting. This gave us a first-hand and up-close appreciation of the challenges faced by teachers and ideas on how technology can be harnessed to address some of these challenges which we may not have otherwise appreciated in the same way or to the same extent. For example, use of the themed content was an idea derived directly from observing teacher–child interactions first hand in real-world settings. As such we strongly recommend HCI researchers to not only try to understand (for example through reading) but also experience the application domain first-hand as much as possible.

- **Iterative and incremental research and development**: we found the combinations of Action Research as an iterative research method, UCD and Participatory Design as the design approaches, and Scrum as an iterative and incremental software development method particularly apt for designing and developing this educational game. The iterative and incremental nature of these methods allowed us to incorporate changes efficiently and swiftly into the software based on feedback from teachers and evaluation by children while accounting for all aspects of research, design, and development. For example, the addition of features such as a tangible in the form of a dice to avoid accidental starts/selections and ‘uncover correct answer’ (Fig. 5) in later parts of the development/evaluation process was possible due to our iterative approach.

- **Designing for collaborative learning**: in designing for the NZ’s ECE context, we gathered requirements from teachers based on the Ako principles that captured and emphasized reciprocal teaching and collaborative gameplay. These design aspects (described in Sections 6.2 and 6.3) include: the use of themed content to enable children’s interest-led learning; ability to dynamically generate content based on multiple themes selection as a means to value children’s preferences; content orientation to support mutual awareness; the design of ‘uncover correct answers’ feature to enable availability of information; the use of tangibles to manifest shared-control in the game; and the deliberate design to exclude scoring mechanism and to support all players finishing their turns for the game to finish to emphasize collaboration over competition. Table 2 captures the alignment between pedagogical and technological considerations by mapping the guidelines for collaborative learning as derived from the NZ ECE context with the design criteria introduced to manifest those guidelines in the software. We believe these criteria for educational software for collaborative learning will benefit researchers and practitioners designing collaborative educational software in similar contexts.

- **Technology as a silent enabler**: our study supports the claim that NUIs allow children to naturally pick-up affordances and interactions with little or no guidance and help users (children and teachers) focus on the task at hand, e.g. learning about numbers through gameplay. We term this aspect of our design as ‘silent enabler’ which relates to the recommendation to re-establish ‘seamless technology’ in designing educational environments through the use of objects and tangibles to extend learning and problem solving [38].

7.5. Limitations and threats to validity

The choice of the ECE center was largely based on proximity of the center to our research lab which greatly facilitated practitioner (ECE teachers) collaboration in the design and development, and participation of the users (children and teachers) in the various phases of implementation and evaluation. Given the variety of age groups and cognitive abilities, it was difficult to elicit proper verbal responses from all children following children–teacher trials. The questions asked to children yielded a range of responses from very excited, clear answers to no response at all. In particular one of the questions was “What else would be fun to play on this table?” We hoped to get ideas for future work from responses to this question. However, it proved to be too complicated for the children and elicited no proper response. These limitations mean that the results summarized in Table 2 do not contain as complete information as it could have. However, we could not have in any way urged children to respond beyond what was normally attempted by the teachers. We discuss other useful measures to elicit response in future studies in the next section.

7.6. Lessons learned and future work

We learned a number of lessons from this research which we aim to incorporate in our future research efforts in the same and similar domains. These include:

- **Evaluations**: we plan to better the response rates and also better capture dimensions of ‘fun’ experienced by children which are identified as expectations, engagement, and endurance [54] using established toolkits such as the ‘smileyometer’ and the ‘fun sorter’ [55]. We also aim to evaluate how well children remember the tasks after a delay by conducting a second set of evaluations after a few weeks or months have passed.

- **Novelty and Replay-ability**: in order to retain engagement, a series of themed content and different game frameworks may need to be developed. Also, while our game used the familiar framework of the ‘bingo’ game, it would be interesting to study children’s response and engagement with non-familiar games. However, such novelty effects of the game and themed content can only be assessed through a longitudinal study in the future.

- **Participant groups**: in future studies, we would like to have more control over the composition of the participant groups in order to study effects of specific aspects on design and evaluation such as gender and age.
Analysis/coding scheme: the analysis of behavior (e.g. gestures, facial expressions, focus of attention, verbalizations, vocalizations, etc.) was done at an informal level within the exploratory context of our game. Future studies will look to employ more formal coding schemes to quantify and report these aspects as much as possible.

Design Approach: finally, our future efforts will aim to better (and perhaps more formally) amalgamate the User-Centered and Participatory Design approaches with the over-arching research framework of Action Research. Also, we will consider more targeted design approaches such as Learner-Centered design [56] and Informant Design [57] for the educational context and Collective Interaction Model for further exploring the role of control and collaboration in the tabletop environment [58].

8. Conclusion

Our study acknowledges the importance of aligning technological and pedagogical considerations and of studying real-life contexts as imperative steps in designing not just usable, but useful software solutions. We conducted a multi-disciplinary study by leveraging the joint participation of software engineers, practitioners, users, and domain experts. Our choice of research and development methodology was a combination of Action Research as a research framework, elements of User-Centered and Participatory Design as the design frameworks, and Scrum as an agile software development framework, confirmed the participatory, evolutionary, and exploratory nature of our study.

Our study demonstrates that interaction with our game was not only engaging and easily understood by young children but also provides evidence that the design features of ‘themed content’ (Section 6.2) and mutual awareness, availability of information, and control (Section 6.3) support reciprocal teaching, collaboration, and collaborative gameplay respectively as promoted by the Te Whāriki curriculum framework. Our application thus offers a valuable new platform for providing new teaching and learning experiences in the New Zealand ECE domain.

Finally, we believe the most effective and powerful technology is one which is a silent enabler, minimizing efforts spent on comprehending and learning the use of technology and maximizing opportunities for engagement and collaboration through bringing domain activities to the forefront. Taken together, our experiences in this study suggest that our game succeeds in being a silent enabler.

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References


