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How do preschoolers interact with peers? Characterising child and group behaviour in games with tangible interfaces in school

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ABSTRACT

Learning social skills is an important part of the socialisation process of children, which should occur at school, at home and in any place where children live. There are very few studies on social interaction and collaboration roles with 3–4 year old. In this paper, we aim to understand collaboration in young children to help them develop their social skills and improve their overall development. To get this, we have designed an observational experiment to monitor and characterise group activity and roles, mediated by technology and using data mining techniques.

First, we have designed a game as a free-play situation where the conditions require interplay of three children with toys and among interaction among peers. Children interacts with game through tangible toys. The environment collects accurate data on children's actions automatically and non-intrusively. We also consider other data from direct observation by psychologists and educators. Then, we have organised a study for groups(triads) of 3 to 4-year-old children playing with this game. We analyse data from 81 children (51.9% boys and 48.1% girls) in groups of three randomly selected.

The work proposes a set of actions in the game and from them a set of indicators, which are used as intermediate measures of observation to analyse the playing process. Social interaction is characterised in 5 levels: Coordination, Cooperation, Collaboration, Troubled and Unproductive; and five roles: Saboteur, Missing, Explorer, Actor, Collaborator and Director. We found that children interact socially, engage in play, help each other and mostly reach the level of collaboration. There are minority cases of non-cooperation (Troubled or Unproductive), with conflict situations or trial and error solving processes, which cause the task to last a long time before it is finally finished. We have also found that children can adopt different roles in the group. Occasionally, there are cases of children who act as conductors, organising the work while others follow.

This work provides a contribution for teachers and educators in the preschool classroom, relating to social interaction. It tells us that young children can play in randomly organised groups, collaborate and take roles, help their peers and learn to do so in classroom games. It shows a learning situation that can serve as an example of how to conduct technology-mediated activities in the classroom to promote social interaction among children in an effective, engaging and motivating way.

1. Introduction

Learning social skills is an important part of the socialisation process of children, which should occur at school, at home and in any place where children live. Specifically, socialisation refers to developing social competence (Rose-Krasnor (1997); Zsolnai (2015)). There are studies demonstrating that, when some aspects of children's learning-related social skills (including interpersonal and work-related skills) are well established, their chances of acquiring the academic skills required to succeed in school and in future academic activities are greatly improved (McClelland et al., 2000). We are interested in studying how children behave with their peers in a social environment because (Kontos and Keyes, 1999) "by understanding how children interact with the environment and persons within that environment, we can understand how

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the environment promotes children's learning and development." Our aim is to look at collaboration in children beyond play, in learning tasks, showing that it is possible for small children to communicate and perform more complex tasks together. This study summarises an investigation in which the aim was to observe and characterise the spontaneous interaction of young children (3–4 years old) working in groups.

Developmental studies identify the skills that can still be enhanced at school at these young ages. For example, between the ages of three and four, whether the game is solitary or played in parallel, children know how to keep turns, they show themselves to be collaborators and enjoy effort games, they have explicit language for communication purposes and they can play in groups with two to three members. Initially, children of this age like to give orders. They maintain rivalries with others for the possession of objects, even at the risk of not sharing opportunities, and their logical thinking is personalist as opposed to "not mine", as they attempt to impose their desires. Their thinking is centrist, not taking the perspective of others, and irreversible and is linked to the appearance of things.

Relevant literature includes studies with young children about social interaction and collaborative problem solving from the age of two 2 years (Brownell et al. (2006)), 2–4 year-old (van Schaik et al. (2017)), 3–4 year-old (Cerezo et al. (2015)), 4 year-old (Master and Walton (2012), Rabinowitch and Meltzoff (2017)), 3–5 year-old (Cooper (1980), Warneken et al. (2014), 4–5 year-old (Holmes-Lonergan (2003)), 5 year-old (Kutnick et al. (2008); Hermes et al. (2020); Veldman et al. (2020); Kinnula et al. (2018); Leskinen et al. (2020)).They report that at these ages children have the ability to engage in reciprocal interaction, some of them can collaborate on very simple tasks with peers (when there is a mutual benefit) and can even plan their actions (Warneken et al. (2014)). About 3–4 year-olds, Cooper (1980) concludes that can solve more complex tasks than 2-year-old, can ask each other questions, help each other and explain their actions. These results are consistent with those obtained in the tests carried out in our research, in our case with a serious game through a tangible interface.

Most of these studies about collaborative problem-solving with young children are conducted with groups of two children (dyads). There are very few with triads. Exploring collaboration with triads of small children is a research challenge. Keller et al. (2019) conclude in their study with dyads and triads that "Cooperation seems to be easier for children in dyads compared to triads". As Sun et al. (2022) mention, activities with three collaborating subjects "have seven degrees of freedom (i.e., three individuals, three possible dyads, and one triad) compared to three degrees of freedom with dyads". This gives rise to a greater richness of possibilities for exploring communication and roles in groups of young children. Interactions are more complex and varied, that could result in a tedious task to collect the actions that observe the process of the children by hand or from videos; in our case, this task is simplified by the use of tangible interfaces, which facilitates the task of collecting children's activity reliably and accurately.

Collaborative learning in preschool classrooms requires the design of specific tasks for group learning that challenge children cognitively, promote communication and collaboration, and are motivating at the same time. We propose a playful task but with a certain cognitive complexity (solving a series), with tangible objects in a playful environment in which one can talk but also act. In other words, a real game situation where interaction takes place with manipulative actions and talking to solve a task. A game board is manipulated with tangible pieces, which are picked up, stolen, moved, but also named, pointed at, helped, without the need for highly developed language skills to achieve effective interaction.

We monitor the interaction of the children with the objects in the game and the interaction among peers. In most research with young children, this is done through direct observation by the expert or by taking video that is then analysed asynchronously. It has been said that a problem with collaborative activities is that it is difficult to assess individual activity in groups (Lai, 2011). It is also difficult to exhaustively capture the events that occur during a working session (Hornecker and Dünser, 2009). For our work, it is a challenge to get accurate and reliable data to be able to develop our research questions. We noted that in order to carry it out we needed attributes or indicators to be able to quantitatively measure different aspects of the children's task-solving process and to have the same measures for all cases. The tangible interface was the solution to this requirement. There are two challenges here, how to measure and what to measure.

The aspects arising in a group activity as well as the different roles that the children adopt in the group are examined. In order to find out what the data tell us about children's social interaction when they play in groups, data mining techniques are used.

The motivation of the work is to understand under what conditions we can promote collaboration in young children to help them develop their social skills and improve their development. This will help educators to understand that they have to do group activities with younger children and how they have to do them in order to be effective; an aspect that is not ordinarily addressed in early childhood education.

The paper offers several contributions to the research field: (i) We developed a classroom activity as a free-play collaborative game with tangible interfaces, which automatically collects a large number of events from the use of the system, identified independently for each member of the group. (ii) Experimental work has been carried out with triads of children aged 3–4 years old, who have played in our environment in order to collect data on group interaction in this age group. With these data, we have identified and defined a set of attributes obtained automatically from the tangible interface and from the observation of videos. These are original and generic indicators that will allow repeating experiments like this one in order to make comparisons. (iii) Data mining techniques are applied to make automatic unsupervised discovery of information. Thanks to data processing and the application of intelligent algorithms to analyse group interaction in children, we have characterised the forms of group interaction and have seen that children can collaboratively adopt roles spontaneously and learn in play sessions.

This document is organised as follows. First, we give a short description of the state of the art related to the research of the paper. Section 3 describes the research motivation and outlines the research questions. Then, in Section 4, we include the body of our work with all the specifics and details about the research, participants, methods and results. We continue with a discussion to describe and underline the implications of the work. The paper finishes with conclusions and suggestions for future research.

2. Literature review

2.1. Social interaction in young children groups

When children interact socially in order to achieve something together in a game, they are collaborating while playing. Collaboration is possible thanks to interaction. In a group game, there are interactions with toys and with peers. According to Kontos and Keyes (1999), these interactions with objects are of a simple type because the object is not transformed, whereas those taking place among pairs are social, complex and reciprocal. Kutnick et al. (2008) (referring to children aged 5–7) said:

> "There are few studies that focus particularly on young, school-aged children and provide a coherent approach to effective group working in the classroom without focusing on particular curriculum-based skills. It is imperative to assess the effects of this group working over time as regards classroom learning, children's behaviour and their motivation to work with one another."

And

"Research suggests that young children are not able to display the social and communicative skills required to enhance the likelihood of group-based learning."

Crook (1998) stated that productive interaction in small groups of children is very rare. Kutnick et al. (2008) summarised the reasons: (a) teachers do not usually propose group work among children, and children show dependence on their teachers and are insecure when they are with their peers; (b) the tasks proposed are neither cognitively challenging nor structured to be done in groups; and (c) young children do not have exploratory and elaborate talk when they are in groups. Crook (1998) suggests that it is possible that "children lack certain psychological skills-cognitive prerequisites for effective collaboration".

At the same time, van Schaik et al. (2017) emphasise that young children interact with others, respond to peer actions and can sustain uninterrupted episodes of play by interacting with their peers. They can participate in collaborative activities (Hamann et al. (2011); van Schaik et al. (2017)) if the conditions and tasks make it necessary. Howes and Matheson (1992) found that if completeness increases, they help each other and can share with others. Hay et al. (2004) say that initially relationships tend to be dyadic but then evolve into two or more individuals without it being clear at what exact age this evolution occurs. Ishikawa and Hay (2006) calculated that at the age of two years approximately about 20 percent interact in triads. This percentage becomes higher as children grow and mature.

2.2. Characterisation of collective activity

There are different ways to characterise the activity among groups. Some of these ways are specifically focused on collaborative learning. We consider three different ways to characterise a collective activity (Baker, 2015):

- *C*oordination. A group situation in which one participant organises or directs the work of the others while the rest of the group follows.
- *C*ooperation. A situation in which all members of the group work equally in a synchronised way and with a balanced division of work. These are cases in which each individual comprises a part of the total, either by specialisation or because it is his or her turn to fill that role. In this case, the children communicate in a cordial way, wait for each other and allow the playmates to take part in the task.
- *C*ollaboration. This is a process of social interaction in which a group constructs a solution to a problem by sharing resources and experience through a process of mutual help. It is when a person helps another, explains the mistakes, suggests what to do, waits for the other to think or gives him a clue.

There are two other characteristics that we have found that refer to non-constructive situations (Garton and Renshaw (1988); Barron (2003); Tocalli-Beller (2003); Lee et al. (2015)), that is, when there are conflicts or no progress is made towards a solution and the children are not centered in the task. This may occur because the children are not yet mature enough to work in a group or to understand the task:

- *Troubled*. Non-constructive group situation in which ineffective interactions occur. As a result, group progress is slow or non-existent, making it difficult to achieve common goals and complete the activity. The reasons for this may include, for example, a lack of communication or trust or excessive competitiveness.
- *Unproductive*. In this situation, children communicate and exchange ideas without conflict, but they do not move towards a solution; rather, they wander around, as if they do not want to finish or do not understand the objective of the task.

2.3. Roles in the group

In a group activity, each individual works differently according to his or her objectives, skills and knowledge about the task; he or she adopts a role in the group. In the case of preschoolers, children's actions are even more unpredictable than in adult groups. There are many studies that conceptualise and categorise these ingrained roles.

Druin (2002) takes into account four roles for children in technology design: User, Tester, Informant and Design Partner. Chi (2009) and Chi and Wylie (2014) classify participants behaviours into four categories: Interactive, Constructive, Active and Passive. The result is the ICAP framework. It only uses constructive roles. Kinnula et al. (2018) conclude, in their study on the roles that children adopt for themselves when performing design tasks in technology, that ten roles can emerge, eight of them constructive (meaning according to the authors, that create value), which are Team-Worker, Achiever, Artist, Adventurer, Socialiser, Pleasure-Seeker, Inspired, Leader, and two that do not create value-Conformist and Under-Achiever.

2.4. Observing children and collecting data. Tangible interfaces

In research, it is important to observe children's interactions with objects and peers during play, as they are considered to have ecological validity and may predetermine other measures of cognitive and social competence (Kontos and Keyes, 1999). There are several ways to address this examination. In this context, it is relevant to do it with discretion, without being intrusive and without disturbing the individuals. The device used to perform the activity influences the data collection process and storage process. It is challenging to automatically record and model all the interactions of children when they play freely.

There are many ways to collect data (Fig. 1), ranging from the use of experts who either question the user, with questionnaires or interviews, or analyse the situation synchronously (in-situ) or asynchronously, via video. They then translate their findings into data forms (Basit, 2003). This is a valuable but, at the same time, costly task in terms of time and human resources that can add bias to the data.

It has been shown that children are more willing to collaborate with multi-touch tablets than with classic elements such as pencil and paper (Davidsen and Vanderlinde, 2016). In addition to this advantage, these devices allow children to perform *automatic collection* mechanisms. This allows collecting data while users perform the task, and their measurement is totally reliable, without bias, because it is performed directly by the technological environment. Several studies (Antle (2007); Roldán-Álvarez et al. (2020)) demonstrated that multi-touch tabletops and tangible interfaces are suitable for creating interactive learning environments. Tangible interfaces have the advantage of tablets (multimedia, colours, sounds) and of classic games (use of toys the children are familiar with, which makes the game more natural). They are suitable for addressing learning and fun collaborative tasks (Dillenbourg et al., 2011), primarily with children (Africano et al. (2004); Price et al. (2003)), who interact with the game board using their usual toys. Schneider et al. (2011) studied the benefits of these interfaces for collaborative learning and interaction, highlighting their focus on supporting face-to-face collaborative activities. One advantage of such interfaces is that they establish real learning situations in which it is possible to observe children's behaviour. For the researcher, these are devices that allow data to be collected on the child's activity without interfering with play.

The use of tangible devices makes it possible to collect and automatically process many actions of children: the timing is accurate; the sequencing of events is realistic, reliable (no events are missed) and unbiased. But there are nuances, gestures and verbal or physical interactions that are also important to characterise social interaction and that cannot be collected automatically during a working session (Hornecker and Dünser (2009); Fleck et al. (2009)). That is why a mixed approach is needed to unify the advantages of the two methods for data

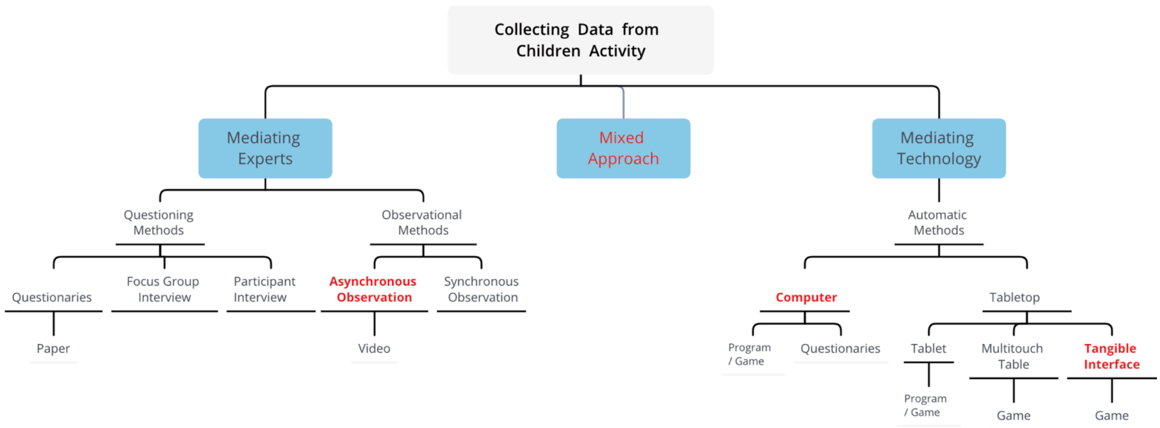


Fig. 1. Taxonomy of data collecting methods about interaction of children (source: authors' own elaboration). The methods used in this paper are in red. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

collection as many researchers have already pointed out (Creswell (2003); Jones (2016); Fleck et al. (2021)). In this way, expert mediated method are combined with technology mediation such as video (Derry et al., 2010), computer logs and tangible interfaces (Westeyn et al., 2012).

2.5. Educational data mining

Learning Analytics, as a field, has multiple disciplinary roots. Dr Wolfgang Greller and Dr Hendrik Drachsler (Greller and Drachsler, 2012) defined learning analytics holistically as a framework that can act as a useful guide to setting up analytics services in support of educational practice and learner guidance.

When learning analytics goes beyond the concept of statistical analysis and joins machine learning and data mining techniques, the idea of *Educational Data Mining (EDM)* arises. A basic tool of EDM is machine learning. There are two classic approaches to machine learning: supervised learning and unsupervised learning.

In supervised learning, the data from which training is performed has a label or class embedded in it. This approach has been used to predict students' learning outcomes (Tsiakmaki et al., 2019), detect student dropout (de O. Santos et al., 2019) at university level and evaluate student performance in primary education (Ramaphosa et al., 2018).

On the other hand, in unsupervised learning, the aim is to automatically differentiate clusters that share similarities in their indicators without an a priori labelling of individuals. This type of learning has also been used, for example, to discover patterns of collaboration and interaction among students as can be seen in Amershi (2009) and Huang et al. (2019).

We have followed the unsupervised approach applied to the discovery of collaboration patterns among preschool children during the performance of a task/game.

3. Research motivation and questions

The aim of the paper is to observe and characterise social interaction of young children (3–4 years) working in groups, supported by technology, specifically by tangible interfaces. The aspects arising in a group activity as well as the different roles that the children adopt in the group are examined. For the research, we have created a fun and learning situation with a board game in which collaboration emerges naturally: children ask for and give help, take another's toy, provide an explanation or do the work for another. Similarly, conflicts may also arise in which one child steals an element of the game from another child, pushes another to take control of the board or disrupts the board. The categorisation of the collaboration modes among children should be obtained by a data mining algorithm and then interpreted by experts. To address this objective, the two research questions of our study can be summarised as follows:

- How 3 to 4-year-old children play in groups? How is the social interaction among them? Do they solve tasks together? Do they help each other? Can they collaborate? Do they adopt roles?
- To address our aim in the paper, we have dealt with a research question about data and their use: What is the role of tangible interfaces in collecting data to study interaction in groups of very young children, and what role can data mining techniques play to discover about children's social interaction and their roles in the group?

4. Methodology

4.1. Participants

A total of 81 3-4-years-old children (51.9% boys and 48.1% girls) participated in the experiment. They were from four different classrooms in the same pre-primary school. The students were randomly organised by their teachers into groups of three. The data of children who had attended early care services because of a developmental disorder were excluded from the analyses.

4.2. Materials: Augmented collaborative game for small children

We have developed a game in which children manipulate toys and establish conditions to observe the social interaction of young children. All the available elements are tangible and have an underlying black-and-white fiducial code (Costanza and Huang, 2009). Children play on an interactive table on which the game is displayed and they can place the toys.

4.2.1. The game: hardware and software

The task has been modelled as a game in which children play with the same artefacts that they use every day. It poses a problem with enough completeness to observe different levels of collaboration and forces children to communicate and coordinate to achieve the goal. The technology provides feedback, and children appreciate it as a fun and playful task.

The software of this game requires children to complete a series of ducks along a river following the initial sequence of colours represented by three ducks (pink, purple and green). It has been designed to be played by three pupils simultaneously, each with a different set of ducks, in order to encourage collaboration between them. Some conditions are established that force the children to collaborate because none individual have all the pieces to complete the game. In order to satisfactorily complete the game, it is essential that everyone participates and interacts. This tangible tabletop game can be played by groups of three children face to face. We used a Nikivision tabletop device (Marco-Rubio, 2011), which has been designed and built specifically for children aged 3–5. The structure of the device for this game consists of the following components (Fig. 2):

- The rubber ducks are the tangible element that children play with. To be recognised by the board, the base of the figures consists of a fiducial marker, that is, a black-and-white marker with a pattern that makes it possible to track the figure on the table, detecting its position, orientation and size. This enables the manipulation of conventional toys on the tabletop surface by sticking a printed fiducial marker (Costanza and Huang, 2009), (Kaltenbrunner and Bencina, 2007) on the base of the toy.
- A translucent board on which the game board is projected and on which the children place the figures.
- A camera that can capture the fiducial markers of the figures through the translucent panel. To do this, an inclined mirror is placed under the board, and the camera collects the images reflected in the mirror. This allows the table to be low enough to be used by children, while the camera can be angled enough to capture the whole board.
- A projector that draws the images of the game on the surface of the board by projecting them onto the mirror, which reflects them onto the translucent surface.
- A computer that runs the game software and allows the visual recognition of the figures through the images captured by the camera and the collection of logs or automatic data.
- A video camera that records the entire game process, both in images and sound.

All the children's manipulations of toys on the tabletop surface are recognised, tracked and recorded by the software and saved in log files. Visual and audio feedback is provided through image projection on the tabletop surface and through speakers.

For researchers, the aim of the game is for the children to collaborate, help each other and "play together" (even learn to collaborate, as there are children of that age who do not do so). For children, the objective of the game is to solve a logical sequence of ducklings of three colours that swim along a river and want to get home. This task is of medium difficulty for children 3–4 years of age. It has been chosen to present a challenge and give children a space to explore in the game. The board is interactive and provides positive and negative feedback to the players as an aid throughout the round. Fig. 3 shows the workflow of the game.

Each group of three pupils plays the series game twice, each time with a different game configuration (see Section 4.2.1), so that the children's collaboration and strategies will also be different. First, each pupil chooses a set of ducks and takes them from the table, keeping them apart. When all the players have completed this task, the game is ready to start. The screen on the tabletop will then show a drawing of a river with three ducks and nine empty places following the course of the river.

As can be seen in the Fig. 2, in addition to the river, there is a sun drawn on the screen above it. If a duck is placed in the wrong place (e.g. a pink duck in a purple duck's place), an error sound will be played, and the sun's face will turn sad. Otherwise, when a duck is well placed, the sun's face will smile, and a quacking sound will be played instead. This feedback given to the pupils is useful for engagement and for minimising the interaction with the teacher/researcher. Therefore, pupils can check by themselves whether or not their duck is correctly placed.

There are two configurations for the game: (i) Single-colour: each child has a set of ducks of the same colour (Fig. 4a); (ii) Multicolour: each child has a set of ducks consisting of the three available colours (Fig. 4b). In the Single-colour task, the child first receives a set of ducks that are all the same colour, so the path cannot be completed without

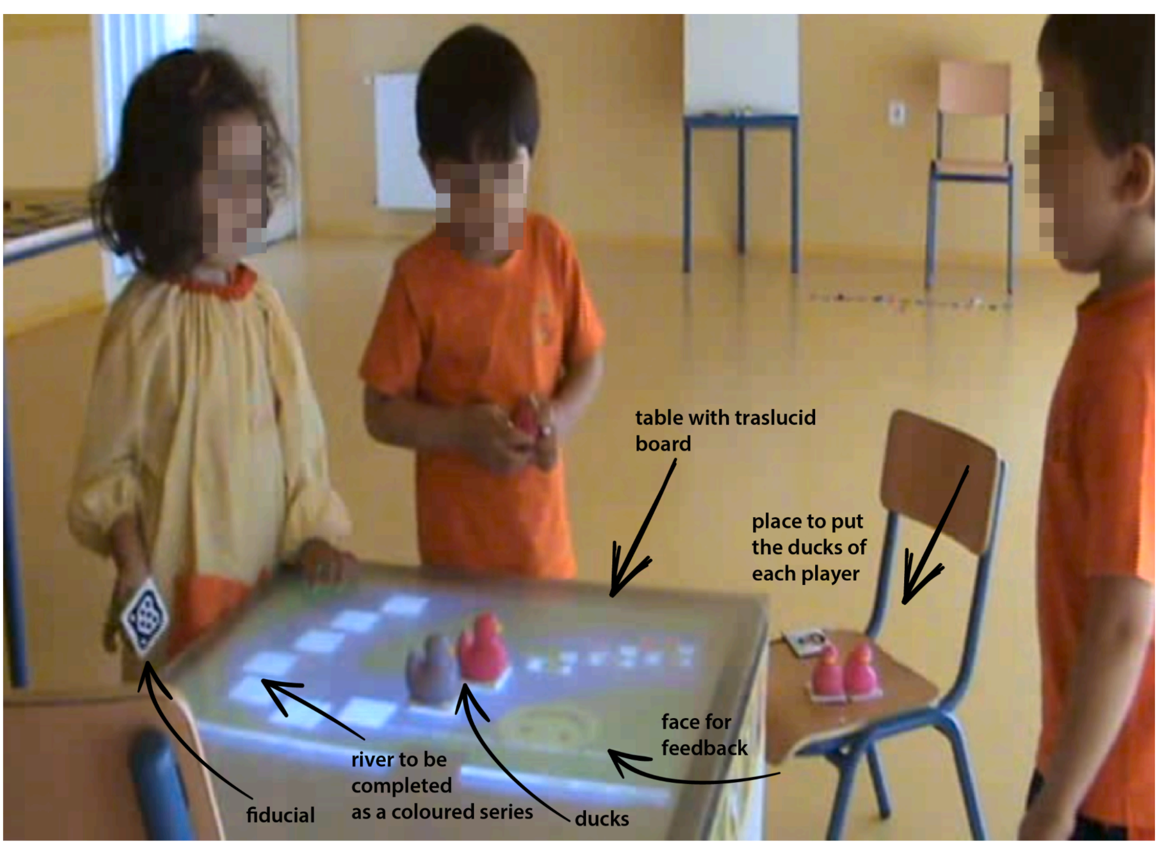


Fig. 2. Tabletop of the game.

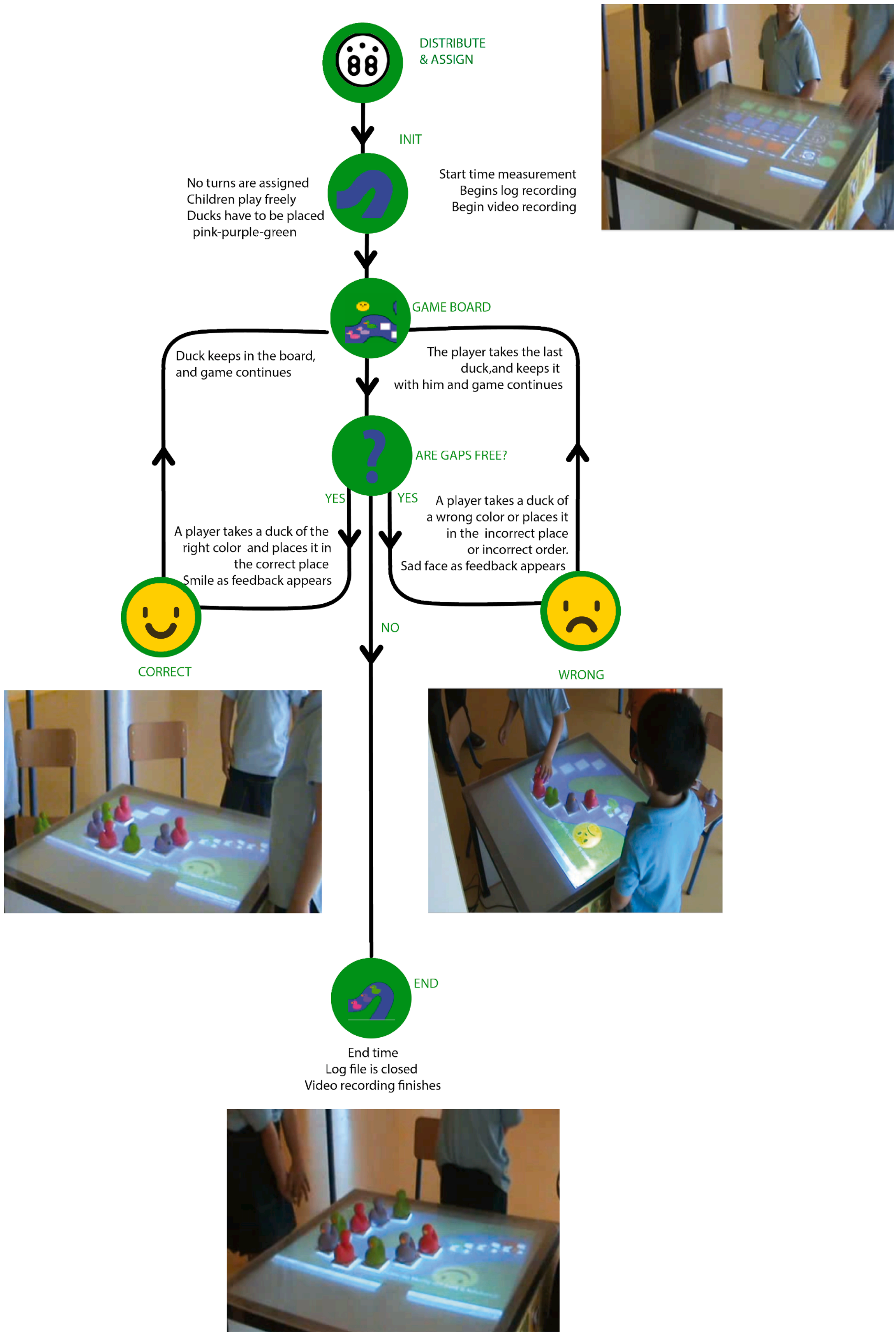
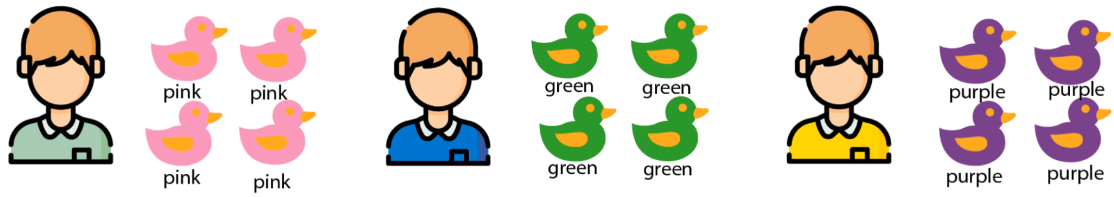
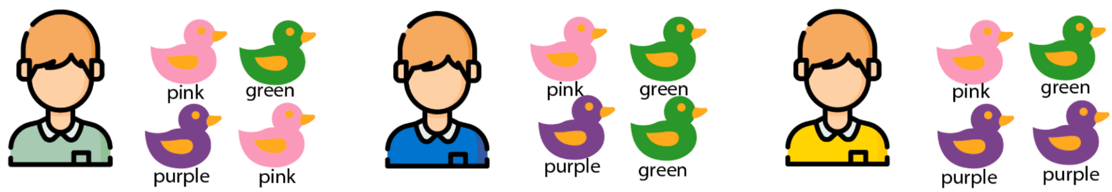


Fig. 3. Workflow of the game.



(a) Single-colour configuration: each child has ducks of the same colour (icons from flat-icon-.com)



(b) Multicolour configuration: each child has ducks of different colours (icons from flaticon.com); each child has at least one duck of each colour, although they may have two or more ducks of the same colour.

Fig. 4. Game configurations.

collaboration involving the pieces of the other two partners. In the Multicolour task, each set contains ducks of the three available colours, so each child can place his or her ducks without considering the rest of the team members, although this behaviour would not allow the team to complete the path.

These configurations allow us to construct short-time game situations in which social interaction is essential, and in such conditions, to observe how the children approach these situations in the group. A certain degree of collaboration is mandatory because no pupil has enough pieces to solve the puzzle by himself/herself, and the colour sequence makes the children follow turns. However, it does not only involve waiting for turns, as pupils can also help each other by talking or even by taking their partners' ducks and placing them correctly to continue the sequence. To detect these interactions, video recordings were used to gather complementary data for analysis.

4.2.2. Roles

In our work, we are going to consider six roles, four constructive and two disruptive. They have emerged from the problem study and observational analysis of children playing in a collaborative environment:

- *Saboteur.* He/she is not part of the group. This player does not get involved in the task but only does meaningless things that disturb and spoil the work of others.
- *Missing.* He/she does not participate in the task or shows any interest in it but limits him/herself to observing and sometimes nodding.
- *Explorer.* His/her understanding of the task is superficial. The player takes part in the task but participates using the trial-and-error method.
- *Actor.* He/she understands the tasks and is able to do his/her part because is more reflective and observes his/her peers.
- *Collaborator.* The player has a broad comprehension of the task, follows the solving process, understands the actions of others and can explain the task to peers. He/she participates and helps partners.
- *Director.* He/she has a deep understanding of the task and directs it. Instead of explaining it to colleagues, he/she tells them what to do.

4.2.3. Actions and attributes

Information about the game was collected both automatically, using Nikivision software, and manually, through video-recording of the game sessions. The tabletop software kept log files of each session. To this end, after the distribution of the rubber ducks, the children registered on the table using their photos, which were also associated with a reliable marker. For this purpose, the children, assisted by the supervisors, placed their photo on the table and then the three ducks that had been assigned to them in the distribution.

The actions that are recorded automatically are identified in the dashboard by time and by user. Based on these data, indicators are obtained. Importantly, when a child places a duck on the board, the action may or may not be correct. It is not correct when the duck is of a wrong colour, when it is placed on a square that is not the next empty square or when it is in a position on the board that is not a square in the river's path. The collected data are listed in Table 2.

4.3. Procedure

Fig. 5 shows the workflow of the experiment. The children's teacher was present in the sessions, and everyone took part in the games. Before starting the game with the interactive table, the children played individually with coloured chips on a model on the floor, which simulated the path they would later find on the interactive table. In this first phase of the trial, the researchers explained the game and ensured that the students understood what it was and how to complete a mathematical series (children play with the ducks to solve the series). Finally, when all ducks were placed correctly, the software saved a log file containing the exercise definition, the pupils involved, duck assignations and a record of all the events that occurred during the game.

Table 1
Child actions in the game (own elaboration) .

ACTION	DESCRIPTION	SOURCE	COLLECTION
TAKE1	Take own duck and put it on the board	From board	Automatic
TAKE2	Take another partner's duck and put it on the board	From video	Manual
TAKE3	Take the duck and give it to the partner	From video	Manual
TAKE4	Remove a duck from the board that was already well placed	From board	Automatic
WAIT	Waiting for colleagues to put in their pieces	From Board	Automatic
HELP1	Indicate by talking or pointing to a colleague what colour the next piece should be	From video	Manual
HELP2	Indicate by talking or pointing out to the group what colour the next piece should be	From video	Manual
HELP3	Other conversations/explanations about the task	From video	Manual

Table 2
Data used to calculate the attributes .

NAME	DESCRIPTION
Event	Every action of putting a duck on the table by an individual
Hit	An event where a duck is correctly placed on the board by an individual (Own Hit or Given Hit)
Own Hit	An event in which the individual's duck is correctly placed on the board
Given Hit	An event in which a duck from a partner is correctly placed on the board
Received Hit	An event in which a duck of the individual is correctly placed by a partner
Failure	An event in which an individual's duck is placed in the game incorrectly (Own Failure or Given Failure)
Own Failure	An event in which an individual's duck is incorrectly placed on the board
Given Failure	An event in which a duck from a partner is incorrectly placed on the board
Received Failure	An event in which a duck of the individual is incorrectly placed by a partner
Time	Number of seconds of the game played by the group
Attempt	The first time or the second time that the individual plays the game
Task type	Game configuration (*Single-colour* or *Multicolour*)

The study is conducted at the individual and group levels. In both cases, it is based on every action that a child performs on the game board to a set of clusters, with the intention of studying how young children collaborate.

The game was carried out by 18 groups of three children each. Each group performed the task twice, once for each game setting, resulting in 35 game sessions (one of the groups was only able to perform the game once). Every action performed by the children was recorded by the system in a log file (Tóth et al. (2017)). Later, each activity was analysed by an expert, who labelled the level of collaboration in the activity and the role assumed by each child. From these game records, automatic processing was performed, which generated two sets of data: one describing each activity and the other recording the child's performance in each activity.

Of the 18 groups, 7 groups performed the single-colour task on the first attempt versus 11 groups that performed it as the second attempt. Thus, 11 of the groups performed the multicolour task first versus 6 that performed it second (one of the groups did not perform both tasks). A statistical analysis shows that there is no significant statistical difference between the diverse attributes (time, total number of hits, etc.) when performing either task first or second. This is probably due to the small number of samples. Even so, the *attempt* attribute has been kept in the set of attributes used to perform the clustering described below in order to analyse whether any of the clusters is predominantly made up of groups that perform the task on a first or second attempt. Thus, as will be seen below, it has been observed that cluster 2 is formed by groups that perform the task first and cluster 3 is characterised by groups that perform the task second.

A similar analysis was performed for the individual data. Similarly, no statistically significant differences were found between performing a task first or performing that same task second except for the attributes *Total Number of Events* and *Number of Given Hits of the Game* for the single-colour task. Therefore, we do not consider that there is enough data to establish a significant difference and perform a full analysis of the difference in performance between performing a task first or performing it second. Furthermore, such analysis would move away from the focus of this article on collaboration among children and would rather fall within the scope of the study of task learning.

4.4. Methods: clustering algorithm to observe the collaborative game

Once the datasets for the analysis of the group task and for the individuals (children) were obtained, a clustering algorithm was applied to detect the different groups of behaviour both at the group level and at the individual level for each child. An outline of the complete process can be seen in Fig. 5. The process was applied in a similar way and independently of the task dataset as well as of the individuals.

First, a clustering algorithm was applied to obtain the different groups of behaviour described by the data. For this process, the classification given by the experts regarding to the development of the task, or the role assumed by each child in its realisation were not taken into account. The algorithm computes the clusters only from the data collected automatically from the table. The clustering algorithm used in this step was the k-means algorithm (Arthur and Vassilvitskii, 2007).

The objective of this paper is not to generate an automatic classifier of groups or children to perform either of the two proposed tasks. If this were the objective, it would be a case of supervised learning in which models more oriented to this type of problem (such as decision trees) would have to be taken into account. Instead, it is part of the objectives of this article to verify that a machine learning model can automatically detect collaboration in groups of children and their individual behaviour within each group. Therefore, no extra information provided by external experts has been used either for the generation of the clusters or for the evaluation or selection of prior attributes. That is, no a priori information on the behaviour of the groups or individuals has been used beyond what was observed during the exercise. The data provided by the expert (degree of collaboration of the group and role of each individual) have been used a posteriori to evaluate the knowledge obtained by the clustering process and to verify that this knowledge is consistent with the observation made by the expert.

The probability distribution of the degree of collaboration in each cluster was then calculated, assigning to each cluster the most frequent degree of collaboration among the experiences that form the cluster. Based on this assignment, we evaluated how many experiences corresponded to a cluster with the same degree of collaboration or belonged to a cluster with a different assigned level. This percentage was used as a performance measure of the clustering calculated by the k-means algorithm. The number of clusters in the k-means algorithm was adjusted to maximise this performance measure. Table 6 shows the proportion of

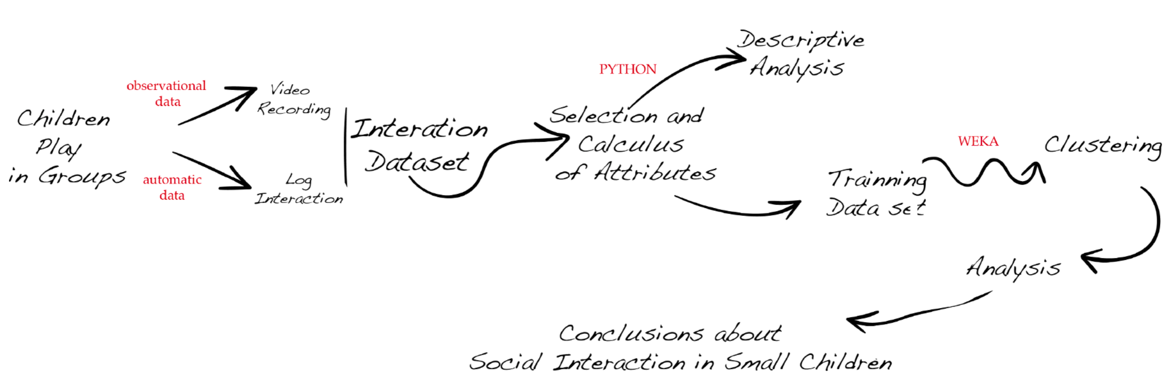


Fig. 5. Workflow of the experimentation.

the degree of collaboration present in each cluster.

5. Results

5.1. Dataset

Two datasets have been calculated. The first one, at the group level, in order to study the different levels of collaboration in each group. The second dataset contains information on the performance of each child within the group. This dataset has been used to analyse the different behaviours of each individual within the group.

5.1.1. Dataset at group level

The first dataset describing the activity consists of 35 samples (one for each activity) and contains indicative attributes about the group development of the activity. Therefore, this dataset does not include specific attributes about how each child performed the activity. Table 3 shows the descriptive analysis of the variables of the group data (Gil, 2019).

5.2. Dataset at individual level

The second set of data is aimed at analysing each child's individual behaviour. Table 4 shows the descriptive analysis of the variables of the individual data (Gil, 2019). It consists of 105 samples (35 games with three children per game). Therefore, each sample corresponds to the completion of a task by a child. Each sample is made up of 34 attributes. These attributes describe both the task and the child's performance during the task. Thus, attributes have been added to those of the first set of data, such as how many events the child generated in the task, how many of them were successes or how many successes were achieved due to instructions given by another child in each task.

5.3. Precalculations

Some attributes have been calculated, in a data preprocessing phase prior to the application of clustering algorithms, from the records automatically stored by the system.

In addition, the behaviour of each child has been analysed by an expert, and an attribute has been added that classifies the child into one of the group roles described in Section 2.2.

As a consequence of the addition of these calculated attributes, dependency relationships between attributes are produced that can affect the learning process as described in Jakulin and Bratko (2003).

Table 3
Descriptive analysis of the group attributes (N=35 in all cases).

	Id. attribute (Table 5)	Min.	Max.	Means	Standard deviation
Attempt	`Attempt`	1	2	1.4857	0.5070
Time	`Time`	60	710	185.97	129.386
Total number of events	`# Events`	9	35	15.34	5.657
Total number of hits	`# Total Hits`	6	22	9.31	2.410
Total number of failures	`# Total Failures`	0	17	6.03	4.860
Hit rate	`% Hits`	0.261	1.000	0.664	0.206
Failure rate	`% Failures`	0.000	0.739	0.336	0.206
Number of given hits of the game	`# Given Hits`	0	5	2.03	1.562
Number of given failures of the game	`# Given Failures`	0	1	0.23	0.426
Percentage of given hits	`% Given Hits`	0.000	0.500	0.22	0.173
Percentage of given failures	`% Given Failures`	0.000	0.500	0.034	0.091

Table 4
Descriptive analysis of individual attributes. (N=105, all cases) .

	Id. attribute (Table 7)	Min.	Max.	Mean	Standard deviation
Number of child events	`# Events of the Children`	0	16	5.11	3.277
Percentage of child events	`% Events of the Children`	0.000	0.778	0.333	0.185
Number of hits of the children	`# Hits of the Children`	1	13	3.10	1.308
Number of child failures	`# Failures of the Children`	0	12	2.01	2.540
Number of child own hits	`# Own Hits of the Children`	0	12	3.10	2.080
Number of child own failures	`# Own Failures of the Children`	0	13	2.01	2.607
Number of child given hits	`# Given Hits by the Children`	0	4	0.68	1.156
Number of child given failures	`# Given Failures by the Children`	0	1	0.08	0.267
Number of child received hits	`# Received Hits by the Children`	0	3	0.68	0.966
Number of child received failues	`# Received Failures of the Children`	0	1	0.08	0.267
Percentage child hits	`% Hits of the Children`	0.111	0.591	0.333	0.094
Percentage child failures	`% Failures of the Children`	0.000	1.000	0.295	0.319
Percentage child own hits	`% Own Hits of the Children`	0.000	1.000	0.649	0.338
Percentage child own failures	`% Own Failures of the Children`	0.000	1.000	0.304	0.313
Percentage given hits	`% Given Hits of the Children`	0.000	0.667	0.139	0.210
Percentage given hits of the children	`% Given Failures by the Children`	0.000	0.500	0.02	0.081
Percentage received hits of the children	`% Received Hits by the Children`	0.000	1.000	0.235	0.334
Percentage given failures of the children	`% Received Failures by the Children`	0.000	1.000	0.039	0.173
Maximum continuous hits	`# Maximum Hits in a Row`	0	9	2.46	1.861
Maximum continuous failures	`# Maximum Failures in a Row`	0	12	1.46	1.995
Percentage maximum continuous hits	`% Maximum Hits in a Row`	0.000	1.000	0.560	0.376
Percentage maximum continuous failures	`% Maximum Failures in a Row`	0.000	1.000	0.237	0.272

However, we thought it is important to add these attributes as, for example, the hit ratio (which is calculated as the number of hits divided by the total number of events). These attributes, heuristically, are commonly used in teaching to evaluate learning performance.

Therefore, we can consider that there are four types of attributes: the attributes obtained directly by the interactive table as, for example, Total Number of Events; the attributes obtained through observation of the videos as, for example, Number of Hits Provided; the calculated attributes as, for example, Hit Ratio; and the class assigned by the expert to each group and child by giving a level of collaboration to the group and a role to the child. However, it must be considered that the difference between the attributes measured on the table and those obtained through the observation of the videos is only circumstantial since it is due to the limitations of the hardware to capture all the nuances of the game. Improved hardware would allow this information to be captured automatically. Only the classification performed by the expert requires human intervention. Moreover, the information provided by the expert was used exclusively for the evaluation of the results and not during the clustering process.

Thus, we can consider the existence of two types of human collaborators in the generation of the data: observers of the videos whose task is to record some events manually as, for example, when a child places the duck of another child to generate a given hit; an expert able to evaluate the behaviour of the children and establish the classification of the level of collaboration achieved by the group and the role assumed by each child during the task.

5.4. Final results

Fig. 6 shows the data flow (and the related tables included in this paper) for the process described in Fig. 5.

Two parallel and independent studies were conducted. First, data on the performance of the task were considered from the point of view of group activity and the level of interaction/collaboration attained by the group. Second, the role assumed by each child during the performance of the task was analysed individually.

5.4.1. Analysis at the group level

In the first study, five groups (clusters) of different behaviours were identified. In Table 5, the attributes[1] and it is used to compute the clusters, and the centroids that define each group can be observed.

Each of these clusters has been assigned the degree of collaboration attained by the group that appears most often in the tasks that form the cluster. Table 6 shows the probability distribution of each class within each cluster. Therefore, this table relates the labels assigned to each task by the expert (corresponding to the type of collaboration, as described in the introduction) to the groupings made by the algorithm with the data collected automatically. The analysis of these clusters attempts to answer RQ2, “what role can data mining techniques play to discover about children’s social interaction and their roles in the group”.

Analysing the centroids of each cluster, the most frequent type of collaboration in each of them can be observed:

- Two clusters representing task groups in which collaboration was achieved (clusters 0 and 2). Cluster 0 shows the efficiency of collaboration in accomplishing the task. Most of the groups in this cluster have previously performed the task, so they understand the task correctly. If we add to this that they work in a collaborative way, we can see that the time required to accomplish the task decreases significantly. This value (90.8571) can be compared with the time value of a cluster without collaboration, such as cluster 1 (162.333), which is statistically significantly higher according to a *t*-test. This value (90.8571) can also be compared with the average time for the second attempts of each group (192.272727) using a Mann–Whitney test and is also statistically significantly lower than the average time required by each group in its second attempt.

  This difference is not as important in cluster 2 since it corresponds to cases in which children were facing the task for the first time.

  However, the success rate (0.8025) is statistically significantly higher than the average for the first attempt of each group (0.591192).
- A cluster (cluster 1) corresponding to the tasks that only achieve coordination.

  In the absence of efficient collaboration between children, the time required to complete the task is greater than the time required for groups in cluster 0.

  Compared to a primarily collaborative cluster, such as cluster 2 (% given hits = 0.4333, % given failures = 0.1182), the percentage of given hits (0.0806) and given failures is very low or even 0 since there is no collaboration among the children.
- Cluster 3 is composed of groups on their second attempt. All the parameters of these groups are similar to the other groups on their second attempt, except for the number of hits given (3.6), which is higher than the other groups on their second attempt (1.33). This characteristic of collaboration and cooperation seems to have caused the groups in cluster 3 to take longer (223) to complete the task than the other groups on their second attempt (121.5833).
- Cluster 4 corresponds to the lowest level of collaboration observed (*unproductive*). Its main characteristic is the large amount of time and number of events required to solve the task. Although the number of failures is high, this is due to the trial-and-error process used. This number is higher than in the other clusters.
- No cluster has been identified with tasks with a *troubled* level. This is probably due to the small number of tasks with this performance. The few tasks where *troubled* occurred have been identified as coordination in cluster 1 or, for the most part, as *unproductive* in cluster 4.
- Similarly, *cooperation* has been identified mostly as *collaboration* in cluster 0 or in clusters 2 and 3.

5.4.2. Analysis at individual level

The next analysis focuses on the individual behaviour of children with dataset two (data collected automatically plus observational data from experts). After applying the clustering process, six clusters can be identified (Table 7[2]). Then, the probability distribution of each child’s role in these six clusters is calculated (Table 8).

Table 7 provides a qualitative analysis of the clusters:

- Cluster 0, with the majority of *saboteurs* and *explorers*, shows the highest number of events of all the clusters. This is because these two roles tend to perform random actions in the game. The number of failures, number of events of the children and number of own failures of the children in this cluster are high. Only cluster 3 has similar values, as it has *explorer* characteristics. An *explorer* follows a trial-and-error process, which results in a high number of failures. It is also the only cluster in which children induce others to make mistakes in the game. The latter is a significant feature of the *saboteur*.
- Clusters 1 and 4 are predominantly *actors*. Both have very similar characteristics. The number of own hits is similar to that of cluster 3 (*actor/explorer*) but lower than that of cluster 2 (*director*) and higher than that of cluster 5 (*saboteur/missing*). The number of own failures is less than that of *saboteurs* (cluster 0) and *explorers* (cluster 3) and similar to that of *directors* and even *missing*. This is because *saboteurs* and *explorers* tend to generate numerous failures by acting without a plan or with a trial-and-error strategy, while missing ones tend not to take action and therefore maintain a low failure rate.
- Cluster 2 represents a clear *director* role with some *collaborative* features. A high number of own hits and a number of own failures lower than that of *explorers* and *saboteurs*, together with long

[1] The first column shows the attributes used to generate the clusters. It has been considered that a *given hit* occurs when a child instructs another to correctly place a duck in the game. When the instructions lead to another child placing a duck incorrectly, it is considered a *given failure*.

[2] A *received hit* occurs when a child receives instructions from another child to correctly place a duck in the game. When the instructions lead to the child placing a duck incorrectly, it is considered a *received failure*. *Own hits* and *own failures* are made by each child without help or instructions from another.

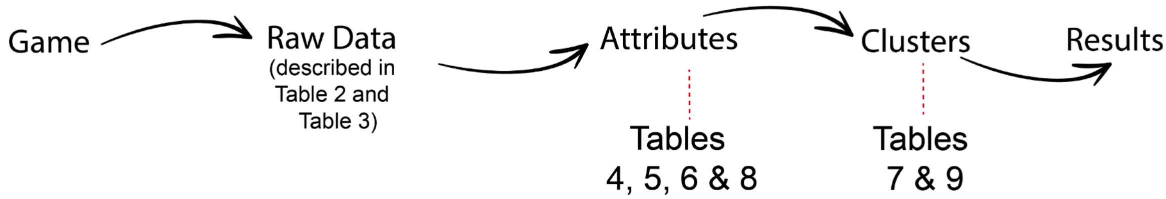


Fig. 6. Experiment data flow.

Table 5
Cluster of tasks (group level) copied from the Weka output .

Cluster#						
Attribute	Full Data (35.0)	0 (7.0)	1 (12.0)	2 (5.0)	3 (5.0)	4 (6.0)
Task type	Single-colour	Single-colour	Multicolour	Single-colour	Single-colour	Multicolour
Attempt	1.4857	1.8571	1.4167	1	2	1.1667
Time	185.9714	90.8571	162.3333	161.8	223	333.5
# Events	15.3429	13.7143	14.3333	12.4	13.8	23
# Total Hits	9.3143	9.2857	8.75	9.2	8.8	11
# Total Failures	6.0286	4.4286	5.5833	3.2	5	12
# Given Hits	2.0286	1	0.75	4	3.6	2.8333
# Given Failures	0.2286	0.1429	0	0.4	0.2	0.6667

Table 6
Distribution of the type of collaboration in every cluster (the most frequent type of social interaction in every cluster is shown in bold font) .

CLUSTER	0	1	2	3	4
Troubled	0.00	0.08	0.00	0.00	0.17
Unproductive	0.14	0.00	0.00	0.00	**0.50**
Coordination	0.00	**0.58**	0.00	**0.40**	0.33
Cooperation	0.29	0.08	0.20	0.20	0.00
Collaboration	**0.57**	0.25	**0.80**	**0.40**	0.00

consecutive sequences of successes, show that the child has mastered the task. The high number and percentage of successes given to other children are characteristic of the role of *director*.

- Cluster 3 shows half-hearted behaviour between *explorers* and *actors*. The behaviour is similar to clusters 1 and 4 (*actor*), but the number of own failures increases due to the *explorer* role's predominance in this cluster.
- Cluster 5 clearly presents a *missing* role. The main feature is a high number of *hits received*. This indicates that the child with this role only acts when a *director* tells him or her to do so or another child performs his or her task. In addition, in this cluster, the number of received hits by the children is greater than the number of own hits of the children.
- The fact that there are three clusters in which there is a significant number of *actors* (clusters 1, 3 and 4) may indicate that this role does not exhibit homogeneous behaviour. Instead, there is evidence that the *actor* role seems to have different nuances.
- No cluster is identified with the role of *collaborator*. Children with the role of *collaborator* have been identified in clusters with a majority of *actors* and, especially, *directors*. This means that the behaviour of a *collaborator* is fundamentally similar to that of a *director* or that, in tasks where there is only one child with a *collaborator* profile, he or she assumes the role of *director* in the task. According to the expert, the only difference that can be seen in the videos between them is

Table 7
Centroids of every cluster of children copied from Weka output (S-C = Single-colour; M-C = Multicolour .

Cluster#							
Attribute	Full Data (105.0)	0 (14.0)	1 (27.0)	2 (11.0)	3 (12.0)	4 (24.0)	5 (17.0)
Task type	S-C	S-C	M-C	S-C	S-C	S-C	S-C
Attempt	1.4857	1.2143	1.1481	1.6364	2	1.6667	1.5294
Time	185.9714	211.8571	196.0741	223.6364	137.1667	126.9167	242.0588
# Events	15.3429	23.2143	14.2222	13.0909	17.9167	11.4583	15.7647
# Events of the Children	5.1143	9.4286	5.2593	6.6364	7.25	2.25	2.8824
# Hits Total	9.3143	11.7857	8.963	9	8.4167	8.9167	9.2353
# Failures Total	6.0286	11.4286	5.2593	4.0909	9.5	2.5417	6.5294
# Hits of the Children	3.1048	3.9286	3.1111	3.2727	2.75	3	2.7059
# Failures of the Children	2.0095	4.4286	1.8148	0.2727	4.5833	0.1667	2.2353
# Own Hits of the Children	3.1048	4.6429	3.4444	6.3636	2.6667	2.1667	0.8235
# Own Failures of the Children	2.0095	4.7857	1.8148	0.2727	4.5833	0.0833	2.0588
# Given Hits by the Children	0.6762	1.4286	0.3333	3.1818	0	0.2917	0
# Given Failures by the Children	0.0762	0.5714	0	0	0	0	0
# Received Hits by the Children	0.6762	0.7143	0	0.0909	0.0833	1.125	1.8824
# Received Failures by the Children	0.0762	0.2143	0	0	0	0.0833	0.1765
Maximum Hits in a Row	2.4571	2.8571	2.6667	6.0909	1.3333	2.1667	0.6471
Maximum Faults in a Row	1.4571	3.3571	1.3333	0.2727	2.75	0.0833	1.8824
# Given Hits in the Task	2.0286	3.0714	0.6296	3.3636	1.0833	2.4583	2.5882
# Given Failures in the Task	0.2286	1	0	0	0.0833	0.2083	0.2353

Table 8
Distribution of roles in every cluster (the most frequent role in every cluster is emphasised in bold font). Individual level.

CLUSTER	0	1	2	3	4	5
Saboteur	**0.29**	0.04	0	0.17	0	0.12
Missing	0	0.04	0	0	0.17	**0.47**
Explorer	**0.29**	0.3	0	**0.42**	0	0.29
Actor	0.07	**0.44**	0.09	**0.42**	**0.63**	0.12
Collaborative	0.21	0.15	0.27	0	0.21	0
Director	0.14	0.04	**0.64**	0	0	0

that the *collaborator* explains to the partner why the piece is placed, whereas the *director* only orders the movement.

6. Discussion

This article describes an activity children with game using tangible interfaces that enables the study of interaction in groups of three chosen at random. The game is set up as a free play situation where the conditions require a certain level of interaction between the children to successfully complete it. As a result, we can say that 3 to 4-year-old preschoolers interact with their peers, know how to take turns, explain to their partner, adopt different roles and know how to build a solution in a group. Other interaction behaviours also appear, but they are not constructive. Stealing from the partner, taking the partner's piece, keeping quiet when the partner does not know what to do or just ignoring the game, not doing anything, are some of them.

Throughout this section we will reflect on the research questions raised in Section 3 of this paper. The first three subsections will discuss the first research question: social attributes about social processes, forms of social interaction in children and roles. The next two sections are about tangible interfaces and data mining algorithms over observational data.

6.1. About attributes to characterise the social interaction process

In our study, we have defined a list of actions that are recorded automatically and manually. From the actions, we have developed a set of indicators that give an intermediate measure of the children's activity. This is similar to the approach taken by adult collaborative learning systems based on conversation models (Gogoulou et al. (2005); Barros and Verdejo (2000); Avouris et al. (2004)) from which they derived indicators to measure the level of collaboration). The indicators of these systems are based on speech acts as the basis for collaboration, while our list of indicators is based on the actions of a face-to-face collaboration with a tangible interface. Our indicators are generic, formalised in a range of values, with specific semantics. This allows them to be used in other studies, thus enabling data to be shared between researchers and results to be compared.

Since the objective of this article was not the implementation of an automatic classifier that models the knowledge of an expert when establishing the roles of each student, no extra information provided by external experts has been used either for the generation of the clusters or for the evaluation or selection of prior attributes.

However, once it has been proven that a clustering algorithm can detect different groups of behavior through the automatically obtained data, it may be interesting to establish which features are more indicative to cluster children into different collaboration groups

In order to answer this question, a comparison of four attribute selection techniques (Gnanambal et al. (2018)) (CfsSubsetEval, ClassifierSubsetEval, GainRatio and ClassifierAttributeEval) shows that the most interesting attributes to perform group-level parsing and classification are Task Type, Total Number of Events, Total Number of Hits, Total Number of Failures, Hit Rate and Failure Rate.

An evaluation of the classifier by clustering shows that the hit rate of the classifier using all attributes is 40.42% compared to 44.92% hit rate using only the most significant attributes. Although the hit percentage after attribute filtering is slightly higher, this value is not statistically significantly different.

In the case of individual data, a selection of attributes shows the attributes Number of Hits of the Children, Percentage Child Hits, Number of Child Failure, Number of Child Given Hits, Percentage Child Own Hits, Maximum Continuous Hits, Maximum Continuous Failures and Hit Rate as the most significant for performing machine learning.

After selecting these attributes, we compared the success rate of the clustering classification model using all the attributes (44.45%) with the success rate of the same model using only these attributes (55.85%). The hit percentage with the filtered attributes was statistically significantly higher with a confidence of 0.05 (not with a confidence of 0.01).

6.2. On the forms of social interaction of 3 to 4-year-old children

Our children organise themselves randomly and we see children interacting, developing play together and adopting roles. There are other studies that say that children perform better in groups if they know each other and better still if they have a friendly relationship (Crook (1998); Hanham et al. (2020)). However, Chung et al. (2017) qualify this statement by saying that performance also depends on the design of the task. In any case, all these studies have been undertaken with older children, adolescents or preadolescents, who had already built a friendship relationships, and not younger children as in our case. As we have seen, in our experiment, the fact that the children are organised randomly and do not necessarily have a previous relationship is not an obstacle to very satisfactory collaboration results. Perhaps this is justified by the design of the task, as pointed out in the studies by Chung et al. (2017).

In all the play sessions, the children always finished the game, although some groups took longer and others. There was no time limit for playing. There were groups that played by reflecting on the state of the game and others who played by trial and error. The latter took longer and produced a large number of events. However, in some cases the extra communication time required to achieve collaboration can make the time needed to complete the task equal to or even longer than when there is no collaboration. The explanation for this can be found in the study of the individual clusters. Individual clusters representing collaborating profiles show a significant number of consecutive hits. This means that a collaborator understands the game and carries it out efficiently. Therefore, the total amount of game time tends to decrease.

Groups that engage in non-cooperative interaction have worse performance on the task, mainly with regard to time but also in the number of events. In the case of non-cooperation, conflict situations are solved by trial and error, which results in a task that takes a long time to finish. The most representative case would be the profile associated with clusters labeled as *unproductive*, where the longest time of task execution and greatest number of errors are observed.

Therefore, we were able to verify that children between 3 and 4 years of age can solve a task not only in a collaboration way but also, when they collaborate, in an efficient one. This translates into better performance in the game. Related to this, note that successes and failures occur mainly when there is collaboration. This is a clear sign that it is at this level of interaction that communication occurs between individuals. Furthermore, it demonstrates that the instructions given by one child to another are an important mechanism for achieving cooperation in these groups of 3 to 4-year-old children. The fact that clusters do not show a clear difference between the *trouble* and *unproductive* group profiles may be due to the small number of such groups or because they are only different degrees of the same behaviour. From this perspective, it would be interesting to carry out a study with a greater number of groups.

What we label as *collaboration* refers to groups where children take turns well and help each other, there is no conflict and no failures occur. Such a scenario is productive and desirable, but it does not happen very often. We observed that the other situation, in which there is a child who plays the role of *orchestra conductor* is more productive for the group. In this case, if the game does not progress, he/she guides (directs) the game and manages to finish it quickly and with few mistakes and no conflict. This makes sense, because-being randomly selected children-not all of them have the maturity and knowledge to solve the problem and if one is more advanced and has the ability to direct the rest, he/she will manages to complete the task efficiently with the group. It is an optimal scenario that also occurs among adults.

6.3. On the roles that children adopt in the group

The roles that have emerged from the clustering algorithm provide consistent and interesting results. First, as expected, *saboteurs* and *explorers* are the children who produce the greatest number of events in the game, since actions are taken without prior planning and at random. In some cases, they are more likely to end the game than to have a clear understanding of it. Especially significant is the fact that *saboteurs* are the only ones who induce other players to make mistakes in the game.

Another interesting discovery refers to the role of *actor*, which has been identified in three different clusters. Two of them seem to be related to the attempt. That is, one of the clusters describes actors in their first attempt at the game and the other in their second attempt. This seems to give an indication of possible changes in the behaviour of individuals when they gain experience with the game. However, this issue is beyond the scope of this article. The other cluster shows a profile halfway between an actor and an explorer. It could be interpreted as an actor who takes longer to understand the dynamics of the game while following an explorer profile, which gives him/her experience in the game. This may be an indication that there are different types of actors or even actors with different understandings of the game.

The role of director is the same as what other authors call *leader*. Leskinen et al. (2020) and Sun et al. (2017) highlight how "Leadership is critical for successful performance of collaborative groups". Normally, the leader, or orchestra conductor, considers various perspectives for the solution or the organisation of the group or the comparison of information. In our conceptualisation of roles, we have distinguished between collaborator and conductor, to differentiate between the child who understands the task perfectly and the one who gives orders or guides the group towards the solution without giving explanations. The collaborator is the one who has a more reflective attitude, waits to see what the peer does, and if he/she does not know, helps him/her with explanations or suggestions. Moreover, there is evidence that the roles of *director* and *collaborator* could be one and the same, conditioned by the rest of the members of the group. That is, a director acts as a collaborator when there are more *directors/collaborators* in the rest of the group, and a *collaborator* acts as a *director* when there are no other individuals who understand the task in the rest of the group. An analysis of this behaviour could lead to different strategies for the formation of class work groups with the aim to encourage collaboration among group members. The collaborator profiles also show a significant number of hits given to other children. This requires communication with these children, which increases the total amount of time required to solve the task despite the high number of hits. In view of the results provided by the data, the distinction between the role of conductor and that of collaborator is diluted. The nuance that differentiated them does not come out in our data. The nuance seems important to us and is distinguished when children are seen playing. Perhaps with more games or other indicators it would be possible for the data to make this distinction.

Table 9 compares the roles identified in this work with those defined by Chi and Wylie (2014) and Kinnula et al. (2018). We do not consider the proposal of Druin (2002), because her approach is very distant from our work since their roles are assigned a priori to individuals and then observed, while in this proposal and in Kinnula the children are put to work and the roles emerge spontaneously. Druin's proposal focuses more on the children's relationship with the pupils who observe the design and with the technology. From the table, our *collaborator* corresponds to Kinnula's *team-worker* and *socialiser*, but in the same way, the *actor* corresponds to the *Achiever* and *the socialiser*. They are subjects who work in groups and help to build solutions. As for the *explorer* role, in Kinnula's proposal it matches the *artist, the creative* and *the adventurer*. In our task, with such young children, there are no options for creativity, so this role –which is very interesting– is not explicitly included in our proposal. The most similar role is the *explorer*. The one that Kinnula calls *inspired* has been difficult to fit into our model. It is literally defined as being "the result of a project creating new aspirations and a strong intrinsic motivation to pursue certain goals". This has not led to alignment with the *director* role, as the children we identified with this role were very goal-focused. Finally, our *saboteur* is aligned with the *pleasure-seeker* role, in the sense that he/she is an individual who does not care about the group and only pursues his/her own fun. When this research began, Kinnula's work had not yet been published, and so a role model was constructed according to our collaborative game. As we have seen, the roles identified are in line with Kinnula's recently published work.

Table 9
Comparison of our roles, ICAP's and Kinnula's roles .

Our Roles	ICAP's Roles	Kinnula's Roles
Saboteur	–Not considered–	Pleasure-Seeker Under-Achiever
Missing	Pasive	Conformist
Explorer	Active	Artist/Adventurer
Actor	Interactive	Achiever Socialiser
Collaborator	Constructive	Team-Worker Socialiser
Director	Constructive	Leader Inspired

6.4. About face-to-face collaborative game and Tangible User Interfaces

We have implemented a playful environment for face-to-face collaborative game-based learning, that is, a tangible serious game with the learning objective of teaching series of three elements, encouraging and promoting interaction in young children. At the same time, for researchers it offers optimal conditions for collecting events and monitoring the interaction process of the group.

In our approach, because children play around a multi-touch screen, they do not have the "asymmetry of action" problem that appears in tablets (Fleck et al., 2009) because only one child can use the tablet, and physically only one child has the device during each turn. In the case of the tablet, there are children who disconnect from the game because they feel they are not participating or want to take it away from their partner. In our case, as we use tangible objects each child has their own tools, this problem does not appear. The children remain physically and mentally engaged in the game, thinking about how to solve the situation so that it moves forward (the sun smiles giving positive feedback) or waiting for the conditions to be met for them to participate (i.e. "I can place my duck"). Depending on the configuration of the game, the pupils do turn-taking as required by the task. In that sense, the environment favours the collaborative action. It is not forced by the device (Fleck et al., 2009) but on the task itself, which makes the interaction more natural.

On the other hand, although the implementation and the game configuration of fiducial are simple, setting up the work environment (Marco-Rubio, 2009) is a task that requires time and care. Zuckerman and Gal-Oz (2013) also pointed this out as the main disadvantage in their studies and experiments comparing TUI (Tangible User Interfaces) with GUI (Graphical User Interfaces). The table used in our experiment is a tailor-made solution to study the problem. When this type of device is commercialised, this disadvantage will no longer exist, offering a simple and motivating tool for teachers to do training with children and for researchers to observe everyday interaction situations.

We have found that the tangible interface used in this study provides a simple and effective mechanism for observing young children in an environment similar to the one they use to play and interact with their peers. It is unobtrusive and allows for the automatic collection of large amounts of data, especially those relating to time and their relationship with the environment, without the presence of the teacher or other external observers.

However, the interface does not provide information regarding the interaction among peers, such as when a child takes a duck away from another, when a child points out to a child which duck is the next to be placed, the explanation one child gives to another or when a child corrects another child. Therefore, our solution was to follow a mixed approach by adding video recording to complete (manually) those missing data.

6.5. On the use of data mining for information discovery in social interaction

We have used data mining with clustering algorithms, following the CRISP-DM methodology. The data analysis began with a basic statistical study of the data, which made it possible to take a closer look at the data available for mining (Tables 4 and 3). In this way, following the CRISP-DM model, the different attributes described were established in order to model them using classification via clustering techniques (Lopez et al., 2012). The clusters discovered during the modelling (Tables 5 and 7) were contrasted with the behaviour observed by experts (Tables 6 and 8) to analyse the different patterns of collaboration and communication of the children.

Clustering algorithms allow us to discover clusters of individuals (in our case, according to each analysis performed, groups or children) with similar characteristics in their attributes. However, these algorithms do not interpret the meaning of the attributes, they only tell us that certain groups have similar values in the attributes (they present similar group behaviours) or that certain children have a similar performance to others as measured through the attributes.

The interpretation of the clusters is a process subsequent to their calculation. This step was performed by contrasting the individuals in each cluster with the label manually associated with those individuals by an expert and a statistical contrast of the attribute values among clusters. This has allowed us to verify that the knowledge obtained from machine learning follows a similar pattern to the labelling performed by the expert. This suggests that the same algorithms could be applied in cases where there is no manual evaluation by an expert, so we can rely on the clusters found to represent patterns of behaviour recognisable by an expert even without the expert's participation.

A different approach would have been to apply classification algorithms in the data mining process as in Hussain et al. (2019). In this case, the objective would have been to discover and emulate expert behaviour when classifying or discovering patterns of behaviour in the individuals (clusters and children) in the study. This discovered knowledge would allow, subsequently, automatically labelling new groups or children according to the values obtained in their attributes during the performance of the same game. However, this approach would not allow extrapolating this methodology to situations without the participation of an expert in labelling the initial data.

7. Conclusions

In conclusion, we have seen that preschoolers can collaborate and will do so spontaneously if the task is appropriate. We have also observed that children naturally adopt different roles in the group. The tangible interface and videos recorded during the game sessions made it possible to collect and analyse data. Based on the statistical studies and clustering algorithms, it was possible to identify various behaviours at the group and individual levels. The different behavioural groups discovered by the clustering process are consistent with the roles observed by the experts.

Two types of analysis of the data collected have been carried out. One at the group level and the other at the individual level.

The analysis at the group level found one cluster whose behaviour is consistent with the *unproductive* concept. This analysis has also found indications that the concept *coordination* defined by the expert is actually the union of two different subtypes according to the indicators: one associated with cluster 1 and another associated with cluster 3 that shares characteristics with *collaboration*. Similarly, the cluster analysis provides indications that there are three subtypes of *collaboration* in clusters 0, 1 and 3, the latter with characteristics shared with *coordination*. On the other hand, there does not appear to be a cluster with distinctly *cooperation* characteristics. The cases of *cooperation*, according to the indicators, have similar characteristics to *coordination* in some instances and to *collaboration* in others.

In the analysis at the individual level, two subtypes of *explorer* can be perceived. One of them seems to share some features with the type *saboteur* (cluster 0) and the other has its own characteristics and differs from the other types (cluster 3). Similarly, indications have been found that the *actor* type is actually formed by three subtypes (cluster 1, 3 and 4), One of which shares characteristics with the type *explorer* (cluster 3).

Implications are that this approach may offer some benefits for teachers and educators in the preschool classroom when addressing tasks such as group organisation in triads and randomly group formation, as well as the advantages of using tangible interfaces and games to promote collaborative behaviour in small children. This paper shows a learning situation that can serve as an example of how to conduct technology-mediated activities in the classroom to promote social interaction among children in an effective, engaging and motivating way.

Modelling how young children collaborate is challenging. This is a small but illustrative experiment. We are currently working in several schools to gather more data and observe whether children adopt similar roles within different groups and in different group game-playing tasks. We are also working on improving our tangible interface to automatically collect a wider range of data. Specifically, we are considering the following ideas: (i) incorporate mechanisms to distinguish when a child takes a duck from another child; (ii) implement automatic video processing mechanisms to detect social interactions; and (iii) incorporate recognition of children's speech during play to recognise representative interactions with group members, such as saying "it's the pink duck", "that's not it" or "the next one is green because it's already pink".

CRediT authorship contribution statement

Beatriz Barros Blanco: Conceptualization, Writing – original draft, Writing – review & editing, Investigation, Methodology. **José Luis Triviño Rodriguez:** Data curation, Software, Writing – original draft, Methodology. **Mónica Trella López:** Writing – original draft, Writing – review & editing, Methodology. **Javier Marco Rubio:** Software, Formal analysis.

Declaration of Competing Interest

- All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.
- This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue.
- The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript
- The following authors have affiliations with organizations with direct or indirect financial interest in the subject matter discussed in the manuscript:

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