Exploring Inter-child Behavioral Relativity in a Shared Social Environment: A Field Study in a Kindergarten

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ABSTRACT
A kindergarten is an interesting community of young children. The children continuously share their interactions and experiences, and grow along similar developmental stages. In this setting, studying relative differences among them can be an interesting approach to investigating how to help their individual and social development. In this study, we present our intuition on inter-child behavioral relativity and apply it to a real kindergarten environment. We conduct a close user study necessitating the monitoring of the children's behavior. Then, utilizing wearable sensor technologies, we perform a field study to explore various interesting aspects of behavioral relativity in an automatic and quantitative fashion. We consulted the kindergarten teachers with our results obtained from our field study in order to validate the practical benefits in the kindergarten environment. We further discuss the potential, limitations, and opportunities of our approach.

Author Keywords
Children, behavior, kindergarten, wearable computing, sensors, relativity

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms
Design, Experimentation, Human Factors, Measurement

INTRODUCTION
A kindergarten[1] is a multi-functional place for children to receive preliminary education, to practice social interaction, and to be taken care of during their parents' working hours. It is a fascinating observational setting as children of similar ages interact and share experiences in the same space and time. There are well-established similarities in their cognitive and motor skills common in each age group [7]. We speculate that sharing a similar situation together may further contribute to certain aspects of their homogeneity.

Our key intuition is that, for such a group of young children, discovering relative differences between individuals and the group may uncover important lessons or wisdom to support their individual and social development. As the group shares more similarities, one's differences from others become more likely points of interest. We use the term "inter-child relativity" hereafter to indicate the relative differences observable between children in kindergartens. We anticipate that understanding the various aspects of inter-child relativity may bring about possible practical benefits for teachers, parents, and eventually children that go beyond a simple list of differences.

In this paper, we explore inter-child relativity by focusing on behavioral[2] representation in a kindergarten setting. This choice comes from the developmental nature of kindergarten children we observed during our user study: due to immaturity of verbal expressiveness, behavioral observation is a dominant tool for teachers to understand their children. Extensive research has also reported that a child's social status [9, 23], developmental progress [25, 26], and talents or skills [8, 22] are related to or predictable by certain behavioral patterns observed when being with other children. These findings inspired us to focus on the behavioral representation of inter-child relativity. First, through the user study, we determined that understanding a child in a relative manner is a practical approach for kindergarten teachers, not only for individual characterization purposes, but also for the customization of developmental direction for the child. For example, teachers encourage a relatively calm child to play with energetic children and vice versa. Second, our study of the teachers' daily, weekly, and monthly tasks revealed a number of challenging points. A specific presentation of inter-child behavioral relativity may be a promising application for assisting teachers in that regard.

To investigate the practical use of inter-child relativity, we conducted an extensive field study of a kindergarten class. To study relativity, each child's behavior should be monitored on equal ground, with accurate and simultaneous data collection. We used wearable sensors equipped with

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[1] Kindergartens in Korean society are institutions for children who are not old enough to attend elementary schools, typically 4~6 years old.

[2] We use the terms 'behavior' and 'activity' to refer to physical behavior and physical activity, respectively, throughout this paper.

accelerometers and gyroscopes, which can quantify each child's behavior with uniform accuracy without human intervention. We prepared 30+ sensors to monitor the behavior of every child in the class. In the data analysis, we constructed several relative metrics to determine inter-child relativity. The results we provided to the teachers are sets of notable differences verifiable through their own observations. Those results remain neutral until validated by the teachers' expertise and experiences. According to the teachers, the major effects of our results include strengthening their judgment with supportive data, enhancing their observations in a finer resolution of time and behavior, and motivating further proactive actions.

The major contribution of this study is threefold. First, we propose inter-child behavioral relativity as an intuitive and effective approach to understand an interactive group of children sharing experiences. Second, we demonstrated inter-child relativity as a measurable representation through wearable sensor technology. Third, we conducted a specific field study and validated inter-child relativity in that setting, yielding promising results for further development.

RELATED WORKS

Making the environment of childhood education "smarter" has been explored since the infancy of sensor technologies. The Smart Kindergarten [27] envisioned a kindergarten environment with sensor-enabled objects, proposing a generic infrastructure including sensor communication and data processing. Recently, sensors and rich media have been widely employed in application-driven ways, as discussed below. To the best of our knowledge, however, little work has been done on exploring the value of understanding the relative behavioral differences in a group of children in a natural kindergarten setting using a sensor-based monitoring approach.

Monitoring children requiring special care

Considerable efforts have been devoted to automated monitoring of children requiring special care [2, 14, 18], focusing on capturing the events of typical self-stimulatory behavior of autistic children. Accelerometer-based motion recognition or audiovisual recording enables capturing such events automatically or semi-automatically. Notably, CareLog [13] extensively investigates the nature of special education and elaborates design principles for a carefully engineered application to support functional behavior assessment. They also present longitudinal field studies with their application. Child's Play [28] addresses the early identification of children with developmental delays and proposes a system to recognize a child's play activity by being immersing sensor-embedded toys in a child's playing behavior. Our work, however, differs in terms of objectives, since our main focus is a group of children with shared experiences, rather than those requiring special medical attention or to capture specific events of interest.

Assessing the intensity of physical activity

Growing concerns about childhood obesity and sedentary lifestyles have motivated the pediatric and sport science communities to monitor the intensity of physical activity with accelerometers, for calorimetry purposes [7, 24]. Their major issues are how to accurately reflect intensity levels of physical activity and how to validate accelerometer data in terms of medical or physical standards. From our point of view, the intensity of physical activity can be a good metric to represent inter-child relativity. We, however, focus on how to reflect the relative differences of intensities among children, rather than evaluating the precise calorimetry per child. To this end, we intentionally do not take the body weights of each child into account when we compute the intensities. This is because we are interested in figuring out whose activity is more or less dynamic in a given situation, not in who spends more or less energy.

Promoting desirable habit formation

Another child-oriented application is to promote desirable habit development. Playful Toothbrush [3] and Playful Tray [19] use pervasive technology to derive persuasive effects on children. With interactive games that respond to a child's actual tooth brushing or eating activities, they motivate the child to improve his or her behavior. Wearable Therapist [12] assesses a child's back posture with an accelerometer-attached shirt. Freier [11] proposes a system for a child to develop proper moral standards through interaction with a virtual agent. In our setting, providing pedagogical guidelines is a sophisticated matter requiring in-depth area expertise. This is not our goal. Instead, we separate the qualification of the analysis results from our internal process because we aim to provide the results to domain experts as an objective reference. Our work can also be differentiated in terms of relativity and group, whereas the above works focus on individual children.

Supporting parental interest in their children

Parental interest in children is high, especially when the children are very young. KidCam [16] provides parents with an instant media-capturing solution to record their children's interesting moments in a semi-mobile way, and Baby Steps [17] presents a system for the parental need to organize and track their children's records. Meaning [20] studies the benefit of both rich expressiveness and ubiquity of mobile media sharing in a kindergarten situation. In our work, increasing parental understanding of children is a potential, but indirect, goal. It may be derivable as we provide the teacher with objective data reflecting the children's behavioral relativity. With such data, the teacher may be able to give parents more reliable and trustworthy opinions regarding their children.

Sensor technologies for social network studies

Another notable application actively employing ubiquitous technologies is the study of social networks and organization dynamics. Choudhury, et al.[4] measured the structure of social networks of a group of participants in a natural setting by applying machine learning on proximity and speech data obtained from sociometers, wearable multimodal sensor devices. More recently, Olguin, et al.[21] studied human attributes in organizational settings with

wearable sociometric badges. They conducted a field study at a real organization and examined the correlation between the sensor data and the organizational human factors like job satisfaction and group interaction. Although assessing the social network or its dynamics among the kindergarten children may not be a direct goal of this study, we believe that understanding children's social interaction is an important aspect where ubiquitous technologies can contribute. The approaches proposed in the aforementioned studies may significantly inspire such an extension.

PRELIMINARY USER STUDY

Understanding the field experiences and challenges in kindergarten education is a priority in finding application-specific support of inter-child relativity, as well as to seek out potential educational benefits. To explore such potential, we conducted semi-structured interviews with full-time kindergarten teachers. We discovered the following: first, the significance of behavioral observation as a tool for providing proper developmental guidance; second, the potential assistive benefit of ground data to act as supporting material for the teacher's observation, memory, and experience; third, the effectiveness of teachers' relative perspectives as a way to understand and evaluate a child; fourth, the challenges of teacher-parent communication, of which we were unaware before this study.

The interview setting

We conducted the interviews at a private, middle-sized kindergarten located in an urban residential area in South Korea. There were eight full-time teachers and 54 children at the time of our study, ranging from 0 ~ 6 years old. (This particular kindergarten has a nursery license as well.) Six of the teachers are in charge of their own classes, comprised of children of the same age. The average number of children per class is 9 (smallest: 5, largest: 12). The average teaching career of these six teachers is 12.7 years (shortest: 7, longest: 20). We conducted semi-structured individual interviews with all eight of the teachers, which lasted 1~2 hours each. The quotations[3] of the teachers' statements are given teacher-specific identifiers. For the six teachers in charge, our questions focused on each of their own classes, whereas we asked the principal and the music teacher about their general experiences.

Observations and records

Methods of recording

We found that there are two organized methods to make records of the children: the diary and the observation records. The diary is a book carried by each child, functioning as a daily communication channel between the teacher and the parents. The teacher also completes a form called "the observation records of childhood behavioral development" on a bimonthly, per-child basis. This form contains 10 categories with 114 specific observation items, on which the teacher makes a (high, middle, low) rating for each. These categories include locomotive, cognitive, and linguistic development, as well as behavioral characteristics such as creativity, friendliness, and aggressive behavior.

Challenges in recording

The challenge in such recording is that it is made ex post facto. For the bimonthly observation records, there is up to a two-month gap between the time of observation and that of the corresponding record. Moreover, many teachers stated that they make the records solely relying on their memory, confessing occasional difficulties in recalling long-term memories of some children. Only one teacher (T3) mentioned taking pictures, which is purely voluntary and burdensome, since she has to organize all the pictures.

The teachers also stated that writing the diaries and making the records creates a considerable workload. Writing the diaries is done within regular work hours every day, which can distract the teacher from paying attention to students. Making the observation records requires rating all 114 items, taking more than one hour per child, so a teacher can usually only afford to fill out the form for one child per day. T6 stated that *"I naturally pay more attention to the child whose form I fill out that day."* Those records might be biased to the latest memories.

The significance of behavioral observation

Insufficient verbal expressiveness

The teachers emphasize observing behavioral aspects to understand a child, due primarily to the dominance of behavior in the children's total expressiveness. The teachers estimate that verbal expressiveness develops gradually, coming close to a degree roughly equivalent to their behavioral expressiveness at the age of 4 or 5 years old. For example, T3 in charge of the 2-year-old class stated that, "*Roughly 80 percent of what I see is from behavior*."

An indicator of personal character and interests

The teachers interpret the behavior of a child not only as communicative expression but also as a good indicator of a child's character and interests. T5 gave examples: *"I capture individual characteristics like timidity, adventurousness, concentration ability, or distractedness from the children's behavior. When the children go to watch a play, some children are so fearless that try to come on the stage and touch the actors wearing beast-like makeup."* The teachers state that certain behavior often represents one's interests or maybe potential talents in a specific subject. For example, T3 stated that, *"When we begin bricklaying, some children rush to get more bricks. But Mike (pseudonym) does not focus on making his own structure; instead, he wanders around, often destroying others' works."*

The effectiveness of understanding the children in a relative manner

From the teachers' perspective, being in a group of similar age is quite natural for children. The teachers have experienced few situations taking care of a single isolated child. For example, T8 stated, *"A single child alone? Well, not in my memory."*

[3] All the quotations are directly translated from Korean.

A prerequisite to discovering a child's social character

Group interaction is a crucial prerequisite for discovering a child's social character. The teachers state that there are many characteristics that are observable *only* in a group situation. Such aspects include friendliness or leadership, seen in how often a child lends his own things to others, how many children follow a specific child, and so on. More sophisticated aspects are about subject-specific interests or disinterests, self-display, etc. T2 stated, *"(indicating the children who rush to get more bricks) They might not have revealed their interest if they were not with others."*

Pursuing balanced education and wide experiences

The teachers state that they actively utilize their understanding of the behavioral relativity of a child to customize the educational direction for each. As T1 stated, *"There's this one child, Mike (pseudonym). He is much more energetic than his classmates, so I often prepare a picture puzzle for him. I would like him to practice being calm, concentration, and delicate finger skills that he lacks."* Similarly, *"Then there is Jane (pseudonym). She is mostly a timid and silent girl. So I sometimes put her into a small group playing games like hide and seek. I would like to give her more experiences of interaction and physical activity."* Identifying what a child has more or less of compared to others can help a teacher develop good guidelines to develop the child in a well-balanced manner with a wide range of experiences.

Providing equal opportunities

Through the interviews, we found that the kindergarten was a kind of jungle with a lot of struggle. T1 stated, *"Children like Mike move faster than others. They often take the good toys faster and have more snacks. It is my job to coordinate them to have equal chances."* To be more specific, *"When the children line up for snacks, sometimes I call children like Jane to give them priority. But, 'sometimes' is important. If I do so too often then they may become dependent on me, and even always expect such exceptions."*

Parents may not be quite open-minded

An interesting discovery is that the teachers express difficulty in talking to parents about their children for several reasons. First of all, the parents' ignorance of their child might be more serious than typically expected. Since dual-income families are common and the demand for early education is high in Korea, children are spending less time with their parents and more at kindergartens. Parents are not always open to hearing and accepting everything about their child, and some remain unaware of their own ignorance. T5 gave us a good explanation: *"I think his mother has her own version of him, most likely one she imagines from her partial knowledge or her ideal."* Some of the teachers concluded that such imagination may produce a bias in the parents' mind, preventing them from accepting the teacher's advice or reports that are not consistent with their ideal. An example episode from T3 is: *"If I say, 'Mike is often distracted and wanders around', then it is not so uncommon to hear, 'No, he wouldn't do that. He is a very silent boy and has good concentration.' Maybe what his mother wants to hear is just praise."* As a result, the teachers state that telling the parents about true observations, particularly unfavorable ones, may not work as intended. The teachers often talk to the parents in a roundabout manner or sometimes even give up.

METHODOLOGY

Our preliminary user study gave us the momentum to further explore our intuition, monitoring inter-child behavioral relativity, in a field environment. In order to design a field study on kindergarten children, we established the basic methodological direction as: (1) inter-child processing of (2) child-worn sensor data (3) to deliver a rich set of organized results in terms of inter-child relativity (4) with potential assistive power for kindergarten teachers to draw finer and supportable assessments.

First of all, inter-child sensor data processing is our prime technical focus in accordance with our preliminary findings. We do plan to process the individual children's data as well, but we treat the individually processed data as primitives for subsequent analysis to construct a representation of the behavioral relativity among the children. By "relativity", we presume a point of reference, a certain degree of common basis within the children's behavioral characteristics. On this ground, we set our preferred monitoring subjects as a group of children at a similar developmental stage who closely share time and space in their kindergarten community by interacting together in the classroom during their daily routine. We monitor the children over various time intervals, in order to find out the individuals' short- and long-term behavioral relativity.

Second, we employ wearable sensors to monitor the physical behavior of each child. By using wearable sensors equipped with accelerometers and gyroscopes, we can collect fairly accurate quantified values reflecting every child's movement. We collect a high rate of raw streaming data so that we can have more freedom in applying diverse analytical methods as well as more potential conclusions to draw. Since we monitor the children for several hours without intervention, we use wireless transfer to acquire the voluminous data. Naturally, we should ensure the quality of the data due to the unreliability of wireless sensor networks.

Third, we aim to deliver to the teachers a rich set of results, in the form of various representations of inter-child relativity. As we focus on inter-child relativity, diverse metrics representing characteristic relativity of one or more children as compared to others could be our main vocabulary. Our preliminary user study supports teachers' understanding of such relativity among their children.

Fourth, from an application-oriented perspective, we expect our results to effectively assist the teachers in providing better education. The results given to teachers are devoid of educational or developmental meaning until the teachers validate and use them as assistive information in order to, for example, support their opinion when communicating

(a) (b) (c)

Figure 1. (a) The sensor (b) The entire stock of sensors (c) A child wearing three sensors

with parents. We discuss broader possibilities of the assistive effects in the discussion section.

FIELD STUDY

We collected data in the form of accelerometer and gyroscope readings transmitted from the children's body-worn sensors. We analyzed the data to find methods for detecting meaningful relativity among children under shared situations. Following that, we consulted the teachers with our results obtained from the full set of data, in order to validate the meaning of each result in terms of the kindergarten environment. The teachers also gave positive feedback, citing children's notable behaviors we were able to bring to light. We elaborate our considerations of the children's safety in the discussion session.

Data collection

The monitored children

We monitored a class of 4-year-old children at the same kindergarten as our preliminary user study. We chose this age group because they were the youngest that could wear our sensors for hours without discomfort, and follow the teacher's instruction to not damage the sensors. Five boys and two girls regularly belong to our target class. The actual number of monitored children varied daily from 5 to 10, because of changes in daily attendance and a joint class session where we could only monitor 10 out of a total of 15.

The sensors

Each child wore three sensors, one on each wrist and one attached to the waist as shown in Figure 1(c). To monitor up to 10 children at the same time, we prepared a total of 30 sensors, plus several spares in case of damage. (See Figure 1(a) and Figure 1(b)) Each sensor is identical in its specifications; all are TinyOS 1.1 compatible, equipped with a 3-axis accelerometer, 2-axis gyroscope, ATmega128 microcontroller, and a CC2420 802.15.4 communication module. We calibrated the accelerometers and gyroscopes at zero acceleration and zero rotation, respectively and used gravitational acceleration for the normalization basis of the accelerometers. We used a sampling rate of 20Hz, which we determined sufficient, given our desired resolution and the stable wireless transfer from 30 sensors at the same time. We assigned one wireless channel for six wearable sensors covering two children, thereby simultaneously using five channels and six sensors per channel.

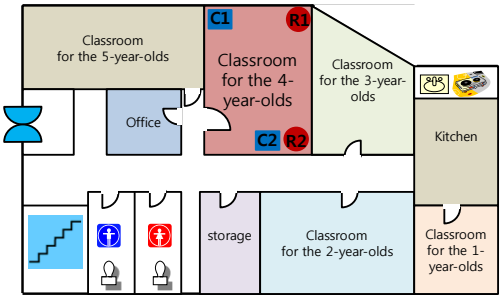

Figure 2. Floor plan of the kindergarten with the locations of 2 receiving platforms (R1, R2) and 2 cameras. (C1, C2)

Figure 3. The classroom with the receiving platforms and the video cameras

The data collection environment and procedure

For one week, we collected data for two to six hours every day, depending on the kindergarten schedule. The daily routine typically consists of several organized sessions and free-play sessions. The organized sessions are initiated and led by the teacher, and all the children in the class are expected to participate. Examples include practicing letters and numerals, drawing a picture diary, and having snacks. In the free-play sessions, the children freely engage in role-playing, brick layering, paper folding, and so on. The children spend most of their time in the classroom, which is approximately 4 m by 8 m large. Figure 2 shows the floor plan of the kindergarten and the instruments for data collection, and Figure 3 shows the overall view of the classroom. We also placed two video cameras at both corners for validation purposes. In addition, at least one of our staff observed the classroom through a window and took notes on the children's daily routine and any significant behavioral differences.

Analysis and results

We aim to deliver to teachers a representation of inter-child relativity in terms of their activity or physical behavior. To make this easy to understand for those without a background in computer science or physics, we first presented behavioral relativity in terms of activity intensities, which is an intuitive metric for teachers. It was presented in two ways: on a daily basis, and in a per class program. We classified 8 major class programs based on the kindergarten's schedules and our observation of their daily routine. Second, we provided an automated partition of some children from their classmates. Here, the children are partitioned into two distinct subgroups every two minutes, based on their feature sets calculated from sensor data. To validate the meanings of these groups, we consulted three

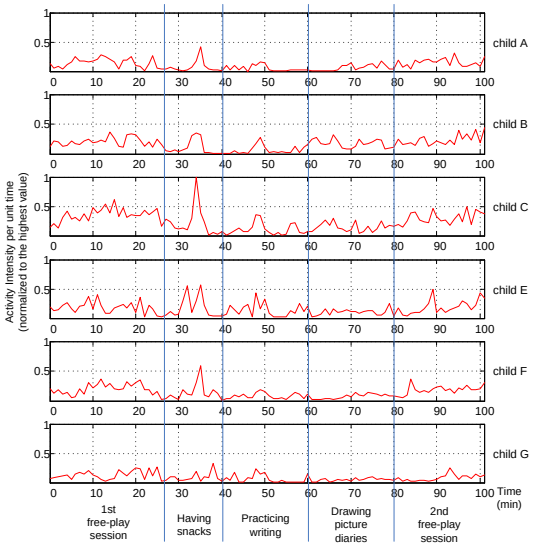

Figure 4. An example of activity intensity per unit time for six children over a part of the kindergarten schedule

teachers to cross-reference the above results with the recorded video playback. Then the teachers assessed how meaningful each result was, based on their own methods of observing the children.

Relativity in activity intensities

As an estimator for one's activity intensity, we evaluated the weighted sum of AC energies per child from the three sensors, since the acceleration at the waist may involve larger body mass than those at the wrists. [6]

For illustration, Figure 4 shows individual time-to-activity intensity graphs of 6 children for a 2-hour period, overlaid with the kindergarten schedule for that day. Figure 5 shows their average activity intensities for the same interval as in Figure 4, and for the whole week. Child D is not shown here since we could monitor him only for 1.5 days. These are normalized to the class average since y-axis values have only relative meanings, and min-max intervals of their daily averages are included in the weekly average.

The teachers confirmed that the overall trend on the graphs matched their routine experiences. T8 said, *"Just like shown here, children are usually most active just after they have some snacks. Then they have a couple of regular programs like writing practice. After that, they have play time again until lunch."* The data shows that Child G might be a slow eater, judging from the relative right-shift of his peak location within 'having snacks'. Cross-referencing the video confirmed that it took about twice the time for him to finish his snack compared to the others. T4, who is in charge of the class, stated, *"I know that Child G is a slow eater, but it was hard to notify his parents of this. This data can be taken advantage of as supporting material. If I had more data like this, I could use it to explain his habits to his parents."* The graph shows that Child G was notably inactive and that child A was the second-lowest in activity intensity. T4 stated, *"I had not realized he was that inactive,*

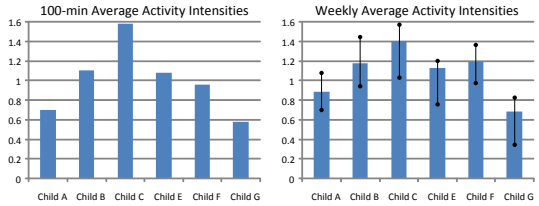

Figure 5. Average activity intensities for six children (Normalized to the class average)

maybe because Child G is so distinctive in my class. I might tend to pay a lot of attention to Child G and less to others."

The relative deviation of activity intensities for each situation

Our next goal for the activity intensity metric is to understand how the relative deviation of a child's activity intensity changes over different situations. The term 'situation' indicates a specific organized or free-play session. Children's interest about specific situations may be represented in terms of their relative deviation from the mean of all the students in a given situation. As mentioned in the user study, a larger (positive or negative) deviation from the mean may imply that a child has a specific interest or disinterest in a given situation. We do not aim to determine a child's interests, but such information could be worthwhile for teachers to note.

We identified the time segments corresponding to each situation for each child. The 8 most frequent situations (see Table 1) are chosen and we collected 232 tuples like:

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(name="Child A", situation="practicing letters",
        duration="10:30:00am~10:38:30am")
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We collected tuples consistently lasting at least 5 minutes to obtain stabilized situations. Various context recognition technologies may help automation but that is beyond the scope of this study. All 8 kinds of situations passed Lilliefors test for the normality of the data with 5% significance. We used the class schedule times to delineate the segments of organized sessions semi-automatically, and manually annotated the segments of play situations.

Table 1 represents the one-week data of the relative deviations of activity intensity per child per situation as a multiple of the standard deviation (σ). There is limited data for Child D because he moved to a different class after 1.5 days. Due to the space limit, we elaborate three specific cases where our findings relate to children's interests, concentration ability, and background. T4 understood the results, shown in Figure 6, well. In the case of 'Listening to a fairy tale', considering its sedentary nature, she agreed that the notable positive deviation can be related to distraction and the negative to concentration. She said, *"In my memory, Child E does not seem to show interest in the tales. He often gets distracted and moves around,"* and, *"Child F shows more talent at narrating tales rather than listening to them."* She also agreed that Child A, B, and G show high levels of concentration. However, the other results posed more complexities. For 'Drawing a picture diary', she strongly agreed about Child E, saying, *"He finishes his drawing very quickly and finds something else*

Situation	Child A	Child B	Child C	Child D	Child E	Child F	Child G
Brick layering	-1.083	0.785	-0.374	N/A	1.617	-0.396	-0.548
Drawing a picture diary	-1.205	0.276	0.615	N/A	1.400	-0.021	-1.064
Having a snack	-0.919	0.245	2.016	0.238	-0.230	-0.608	-0.742
Listening to a fairy tale	-0.856	-0.900	0.122	N/A	1.611	0.663	-0.639
Paper folding	0.076	-1.705	0.600	0.198	N/A	0.830	N/A
Practicing letters	0.876	0.696	0.650	N/A	0.287	-1.035	-1.474
Practicing numerals	0.774	-0.169	-0.099	N/A	1.018	N/A	-1.525
Role play	-1.895	0.028	0.594	N/A	0.585	0.832	-0.145

Table 1. Eight frequent situations and the relative deviations of activity intensities for each child

he likes." However, she noted that Child A and G may not necessarily concentrate well or show high interest. Based on her knowledge, they are shy and not very active, hesitantly looking at others' drawings. In the 'Paper folding' situation, she agreed with the case of Child B who shows a clearly negative deviation. She explained, *"Child B really concentrates on paper folding. She does not move around even a little bit while others often talk to each other and get distracted. This result convinces me of my understanding."* But she pointed out that, *"Child F indeed moves around a lot during paper folding, but maybe because she prefers to come to others and proudly show her work. She might not be deeply concentrating, but she enjoys it differently."*

These analyses indicate that our approach can expose behavioral differences among children in a given situation, and may strengthen teachers' prior understanding. However, making inferences of individuals' interest and concentration should not be done solely based on such results; it requires in-depth understanding of the children's character.

Automatic partition of the minority subgroup of children

Here we extend inter-child relativity to a finer-grained level in terms of both time and activity scales. For every interval of several minutes, we automatically distinguish one or more children whose behaviors may be meaningful outliers compared to others'. The goal of this analysis is to enhance the teachers' practical timescale of observation into a finer resolution. It may deliver novel findings to them. For convenience, we simply named the identified children as the minorities and the remaining children as the majorities without any implication of favorability.

We employ a richer feature set which consists of the AC energies of linear acceleration and the standard deviation of angular rotation rate per sensor. In contrast to the previous analysis of simply taking the weighted sum of AC energies, we preserve the directional components from the waist sensor's readings (x, y, z) for the linear acceleration and (θ, φ) for the angular rotation rate. The directionality of the waist is supposed to reflect the posture variations of the children. The k-means clustering algorithm is applied to the feature set in order to divide the children into the minority and the majority groups, hopefully depending on their behavioral inter-child relativity. During the pilot test, we

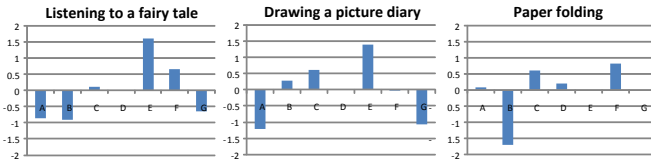

Figure 6. The relative deviations of activity intensities for 7 children in 3 different situations collected for one week

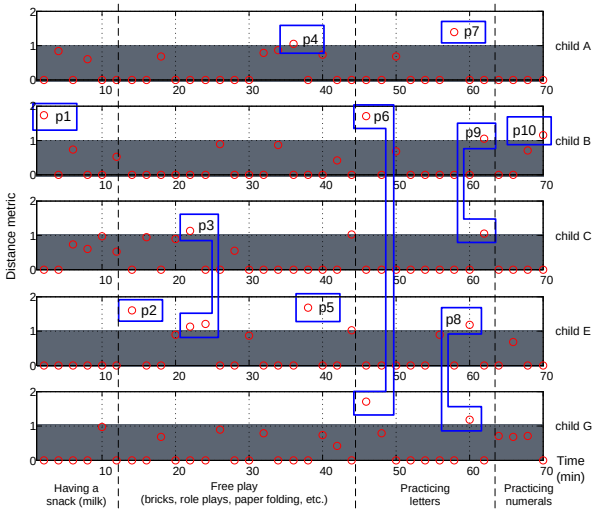

Figure 7. Partition chart for 5 children (The minorities are represented as enclosing polygons. Shadowed regions represent below the threshold of 1.0)

found that applying a global threshold value would filter out many of the ambiguous partitions. We defined the distance metric for the global threshold value as follows:

$$\text{Distance metric} = \log_{10}\left(\frac{\frac{1}{n}\sum_{i=1}^{n}|m_i - c_M|}{\frac{1}{N}\sum_{j=1}^{N}|M_j - c_M|}\right), \text{where} \begin{cases} c_M : \text{the centroid point of the majorities} \\ m_{1\ldots n} : \text{the minority points} \\ M_{1\ldots N} : \text{the majority points} \end{cases}$$

By applying a threshold value of 1.0 chosen through trial and error, we could obtain 9.43 partitioned results per hour on average. (σ = 2.01) For a clear illustration within the space limitations, we elaborate on a part of the results for 5 children as an example (see Figure 7). The horizontal axis is the time line, showing the partitioned results as circles for every two minutes. The vertical axis of each chart represents the distance metric value. If it exceeds the threshold, the child is partitioned into the minorities group.

We consulted three teachers to validate whether the results are plausible partitions or not. We played the two video clips simultaneously recorded from separate cameras, and synchronously displayed the names of children partitioned into the minorities. In the validation of the automatic partition results, we obtained a score of 72% for the overall precision of the results for the entire week, while the precision for those with unanimity was 61%. For every partition, we classified it as 'valid' only if two or more teachers agreed (i.e. an 'aye') that the partition is meaningful. Table 2 shows the 'ayes' and 'nays' for each partitioned result of Figure 7 along with the reasons in case of 'ayes'.

Partition	Teachers' validation for each partitioning (and their reasons)
p1	Aye (Child B is lying on the table on her stomach.)
p2	Aye (Child E left the classroom, and came back a minute later)
p3	Aye (Child C and E are playing 'role play'. The others are sitting at the table while writing something or folding paper.)
p4	Aye (Child A is wandering around.)
p5	Aye (Child E is lying face down on the table.)
p6	Nay (No apparent reason for partitioning)
p7	Aye (Child A is standing on the chair.)
p8	Aye (Child E and G is sitting still. The others are moving around.)
p9	Aye (Child B and C are lying on the table on their stomachs.)
p10	Aye (Child B is dancing in front of the teacher.)

Table 2. The teachers' validation and reasons

Specifically, the teachers showed interest in cases like p1 and p9. Figure 8 shows a snapshot of the video at the time of p1. Child B is trying to lie on the table on her stomach. In the full set of results, Child B showed such actions 17 times. Among the rest of the children, only Child C showed similar actions twice. Our results missed none of these instances. T4 said, *"I had not been aware of this habit. I obviously have seen that behavior. But, I think we have ignored it because it is not problematic or radical behavior."* The teachers added that a single action like this would not be a high point of interest because it was not a serious misbehavior at her age, but that such repetition might need more attention, which they had missed until then.

DISCUSSION

Despite the limited result set obtained from the pilot study, some results prompted the teachers to take action immediately. Until our study, T4 (in charge of this class) had generally thought of Child B as quiet. Our data showing Child B's activity intensity near or above average motivated T4 to observe Child B more carefully. Through instances such as watching Child B climb up the classroom slide, rather than using the stairs, T4 found that although Child B is silent, she is not necessarily inactive. Furthermore, when T8 reported Child B's habit of attempting to lie on the table to her mother, the mother said that Child B once fell at home while doing something similar. This habit is not dangerous in the kindergarten setting, since the furniture is designed for children. Still, the teachers are considering taking safety measures, like installing armrests and footholds. In the case of the slow eater, Child G, T4 observed him closely and found that he chews his food excessively, as strictly instructed by his father. While slow eating can be beneficial to the health, it poses a dilemma to the teachers regarding Child G's socializing opportunities. Because Koreans generally eat very quickly, T4 found that, even at his young age, he is left to eat alone once his classmates have finished eating and left to play together. The health and social consequences of Child G's behavior must be balanced, and some intervention with his father should be conducted. For the latter purpose, prolonged monitoring of Child G's relativity to his classmates' eating behaviors may be helpful.

Figure 8. Child B is trying to lie on the table on her stomach

From these cases, we learned that the monitored results may motivate teachers to take a second look at children's behavior, even if the results are not new or novel. Then they may prompt closer observation and proactive responses.

Potentials for child education and development

There may be potential opportunities for our methodology to help the efforts to provide more customized guidance for children with regard to education, behavioral development, and early intervention. As discussed, with the data of the relative deviations of activity intensities for a given situation, a knowledgeable teacher may be able to utilize the data to infer a child's level of concentration.

Curby, et al.[8] reported that the level of task orientation in kindergarten was a good predictor of gifted enrollment later. This implies that identifying a child with high concentration on a task may provide motivation for early preparation for gifted enrollment. Similarly, we hope to contribute to the efforts to performing early identification of behavioral factors that may relate to future sociability. The field of child development has been exploring the use of behavioral characteristics observed from group interactions to predict a child's social status [9, 23]. Sensor-based monitoring of inter-child behavioral differences might supplement the observation methodology of such efforts, and enable large-scale, longitudinal studies in a cost-effective manner.

Although we have focused on a general group of children, we believe our approach may inspire efforts in child development to provide early detection. Various strategies of behavioral monitoring have been proposed to this end [13, 26, 28]. In the case of a child with an unidentified problem who is sent to a general kindergarten, it may be possible to capture indicative behavioral differences while she is with other children. Such information can be used to a meaningful end, to the benefit of the child, her teachers, and her parents. T4 states that it is a priority to determine a child's propensity for attention deficit or hyperactivity, since those symptoms pose a risk for accidents involving everyone else in the classroom. She adds that its urgency may be an exception to her general caution against the side effects of premature access (discussed in the Limitations subsection). Identifying such clues requires close interaction with both medical and special education experts. Still, the idea of exploiting behavioral relativity of children for early detection of a child with developmental issues may be worthy of exploration.

Potential applications

Independent from this study, we conducted an internal test to study the feasibility of applying behavioral relativity to

group lesson situations in schools. Possible target situations include group gymnastics, dancing, and percussion instrument performance. For example, in group gymnastics, a set of students or trainees performs a sequence of pre-defined, synchronized gymnastic exercises. Likewise, in the case of group percussion performance, children play individual percussion instruments. Both situations described are typical in Korean elementary schools and kindergartens. We specifically tested a set of stretching exercises widely used in Korean schools. It consists of 12 separate stretching motions using the whole body. We had each participant wear 5 sensors and also intentionally asked a participant to modify some motions slightly by stretching less, more slowly, or out-of-synch compared to the rest of the group. The result of our internal test was promising; we could automatically detect most of the events with such differences. This idea may contribute to group lesson situations involving synchronized motions. No matter how large the group is, teachers or instructors will be able to easily identify the moments when a student is performing differently from the norm. Such differences in motion might indicate that the student requires additional instruction. Moreover, for a given student, we may first, help identify which motions the student often struggles with, and second, make a quantitative history of each student's progress during an academic period.

A similar application in the context of group percussion performance may deliver long-term benefits beyond identifying those having motor difficulties, as Overy, et al.[22] reported that poor musical timing skills are highly correlated to dyslexia and spelling ability. It is possible that early identification of children lacking rhythmic skills may help reduce the impact of dyslexia with early treatment.

Limitations

A major limitation of this study comes from specificity. Considering the vast diversity of children and their educational environments, we have demonstrated a case study on a very specific group and setting for a limited duration. Although monitoring the children's behavioral relativity is based on a general idea, its deployment, methodology, and derived results will be largely specific to each setting. The limited duration also poses a threat to generality. For example, although T8 accepted the sudden elevation of activity intensities around snack time as a usual occurrence, a few teachers pointed out that such elevation might differ depending on the menu. Unfortunately, our study duration was not sufficiently long to capture such counterexamples. Another limitation is that we only cover the indoor class activity of our children. In fact, one of the mottos of this kindergarten is learning in the field, so their academic calendar includes several field trips or excursions every month. The data collection infrastructure hindered us from going outside. Thus, this study was conducted on the days without outdoor schedules.

The results obtained from our field study are limited in that they might mislead teachers who are without prior understanding of the children involved. Such a risk is illustrated in the analysis of the paper folding and the fairy tale situations presented earlier. Some teachers raised concerns that in accessing such results prematurely, a misunderstanding or a biased view might develop. They pointed out that general understanding of the children should be developed prior to interpretation of the results.

Children's safety

Our priority throughout the studies was the children's safety. We first acquired the consent of the teachers, and through them, obtained parental consent as well. The teachers examined our prototype sensor design, its physical safety and comfort levels. In pre-study trials, the children liked wearing the sensors, so much so that some without sensors seemed to envy the ones with sensors. After monitoring their responses and behavior, we received final approval. We also planned to remove the sensors immediately if a child expressed displeasure with the sensors. Although such an incident did not occur, we had to hide the exposed power switches after two children had fun repeatedly turning the sensors on and off, posing significant problems for data collection. As the teachers determined it a matter of curiosity rather than discomfort, we agreed to improvise to hide the switch. We will reflect on this to improve the sensor design in a more natural fashion in future studies.

Another issue to be addressed is the electromagnetic field from the sensors' wireless communication. Although wireless communication is prevalent via mobile phones and WiFi, a full guarantee of sensors' safety may be indeterminable due to the rapidly evolving nature of technology. Still, relevant data are available. Our sensor's communication module (CC2420) specifies its output power range as -24~0 dBm at 2.4GHz, or roughly equivalent to 10^{-5}~10^{-3} W. It is far below the nominal power output from GSM phones [1] and a very tiny fraction of the localized SAR limit per body mass (2 $W \cdot kg^{-1}$) [15] even for sensitive tissue. WHO released an official fact sheet stating that no adverse health effects have been established for mobile phone use based on the past two decades of studies [10]. We believe that, for a short-term field study, the aforementioned data can resolve many safety concerns that might arise.

CONCLUSION AND FUTURE WORKS

In this study, we explored the potential of inter-child behavioral relativity with the use of sensors, as a support tool for kindergarten education. Close interaction with the teachers delivered rich experiences that indicate the demand and significance of our idea. The field study in a specific kindergarten, in spite of its limitations, illustrated promising opportunities to use the sensor-aided representation of children's behavioral relativity over multiple dimensions. We discussed the broad spectrum of potential contributions to the body of researches of child development and education. This study was supervised by those in charge of the children's safety, and no child was harmed or forced.

The opportunities explored in this study reveal many fertile areas for future study. Employing multimodal sensors may

enrich the methodologies and the results. Recognizing personal context and peer interaction has been thoroughly explored with wearable sensors [5], which may enable a richer set of elements with which to describe inter-child relativity. Prolonged monitoring of kindergarten children would give teachers chronological data of their children. It would be particularly beneficial for children who transfer to another class, such as Child D in our study. If notable discrepancies in their data appear after the transfer, their new teachers may quickly notice such discrepancies and use the past data to find possible causes. In sensor-enriched kindergartens, a concern that may arise is information overload for teachers. Methodological consideration for unobtrusive support may be worthy of exploration.

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