Characteristics of Eye Movement in the Instruction Process of Teachers and the Problem-Solving Process of Students : The Case of Figure Problems

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Abstract : To facilitate effective instruction, it is important to accurately understand the thinking of instructors during the instruction process and of learners during the learning process. To this end, in the field of pedagogic research, video recordings and protocol recordings have been considered. In recent years, partly because of a demand for more objective data, in addition to past techniques, the usefulness of physiological data has entered into the discussion. In particular, eye movement data, which record where people look, may prove highly useful. It has been pointed out that in the fields of mathematics education, instruction is more difficult for figure problems than calculation problems because less of the solution process is revealed on paper, and it is more difficult to gain an understanding of the thinking process. In this context, eye movement measurement may provide a useful means of understanding the thinking process.

In this study a one-on-one instructional situation using figure problems was postulated, and an experiment was conducted wherein the eye movements of two people, one in a student role and the other a teacher role, were measured. As the students worked on the tasks, they could request hints as necessary, and the teachers, observing the students' progress, could provide hints as necessary. In other words, teachers provided hints when students requested them as well as when they wished to make suggestions. The purpose of this study was to elucidate the general characteristics of the gazes of students and teachers, and to consider the differences in the characteristics of teachers' gazes when requested by students to provide hints and when providing hints spontaneously.

Keywords : instruction, problem-solving, eye movement, figure problems

1. Introduction

1.1. Analysis of the instruction and learning processes

In school classrooms, when teachers give individual instruction and walk around between desks to check progress, they observe the students' solution process, making determinations to offer better advice. When teachers observe students solving problems, they not only check whether the answer is correct but also decide upon their own subsequent course of action. For this, they bear in mind their own specialized knowledge of the problem, practical experiences concerning which points students tend to get stuck on and which wrong answers they tend to give, and the characteristics of individual students they have identified

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through past interactions. Teaching is a complex activity requiring numerous judgments, and ultimately influences children's learning opportunities (Darling-Hammond & Bransford, 2005). Thus, analysis of such processes facilitates teachers' reflection and consideration of effective instruction.

However, the processes of observing students and of determining what types of instruction and advice to give are often carried out unconsciously, and in many respects cannot be understood based on outside observation. Thus, past pedagogical studies have considered means of comprehending the characteristics of such thinking and instruction processes. Nagano & Tengeji (1986) developed a simulation system for diagnosis of learners. During the instruction process, teachers were asked to make judgments regarding students' achievement and to input information on each such determination into the system. This was done with the aim of clarifying the unconscious learner diagnosis process and making teachers aware of the elements and bases of their own diagnoses. Also, the technique of creating video recordings of classes, viewing them, and reflecting on their content has spread globally over the past several decades (Brophy, 2003; Christ, Arya, & Chiu, 2017). For instance, Inagaki & Sato (1996) examined experienced and new teachers, asking them to view videos of classes and to speak up whenever they wished in order to elucidate their thinking processes. The researchers reported that experienced teachers spoke up more often than new teachers and were unique in their logical descriptions of not only their impressions but also their thoughts. Also, numerous studies have suggested that reflection sessions involving video recordings may prove useful in improving teachers' techniques (Castro Superfine, Amador, & Bragelman, 2018; Cherrington & Loveridge, 2014; Christ, Arya, & Chiu, 2012; Rich & Hannafin, 2009; Tripp & Rich, 2012; Vrikki, Warwick, Vermunt, Mercer, & Van Halem, 2017). As traditional video cameras provide only one visual angle, in recent years, some studies have used 360-degree cameras to film the entire classroom (Walshe & Driver, 2019).

In instructing students, it is important to accurately understand their thinking processes and learning progress. Written examinations are the primary means of understanding students' progress, but in addition, observation techniques (behavior observation, error analysis, etc.), face-to-face interaction techniques (interviews, obtaining protocols, etc.), on-paper questioning techniques (questionnaires, etc.) and so on have been used to obtain and analyze data on learning progress (Brown & Quinn, 2006; Taylor, 2008; Zimmerman & Pons, 1986). It is relatively easy to combine several such methods, for instance, by conducting both error analysis and interviews, and these methods have the advantage of analyzing the characteristics of learning progress from multiple angles. Also, they have the merit of incorporating multiple prior techniques and analysis results (Entwistle & Ramsen, 1983).

As demonstrated by the above, it is important to bring to light and examine the thinking processes of both teachers and students in order for pedagogical research to devise better means of instruction. In recent years, there has been a tendency to emphasize evidence-based education, and to place greater focus on data that objectively represent the internal thinking processes of students and teachers (McMillan & Schumacher, 2010; Means, Toyoma, Murphy, Bakia, & Jones, 2009). In particular, further development of measurement devices should provide us with highly objective data collection techniques for measuring physiological data such as brain activity, eye movements, and so on. The Learning Sciences and Brain Research Project, initiated in 1999 by the Organisation for Economic Co-operation and Development - Centre for Educational Research and Innovation, is one such example. The project has built a global foundation for a new interdisciplinary research field incorporating physiology and pedagogy (OECD, 2002, 2007).

Eye movement data, which measure and record where a person looks, are a highly useful form of physiological data, facilitating analysis of the instruction and learning processes of teachers and students. The proportion of stimuli humans take in through their senses is approximately 83.0% visual, 11.0% auditory, 3.5% olfactory, 1.5% tactile, and 1.0% gustatory. The visual sense becomes even more important in teaching and learning in the classroom, making eye movement data highly significant (Ishikawa, 1972). Eye movement measurement techniques, which originated in the 19^{th} century, originally imposed a significant physical burden, but at present, devices that enable safe and easy measurements allow for points of gaze to be measured down to the millisecond (Ohno, 2002). Eye movement is a form of data that measures even unconscious gaze activity, and essentially allows anyone to easily understand "who looked at what, and when," so it has come to be widely used in pedagogical studies as a means of understanding the characteristics of gaze movement in the instructional and learning processes (Lai et al., 2013). For instance, van den Bogert, van Bruggen, Kostons, & Jochems (2014) had experienced and novice teachers view videos filmed in middle school classroom settings, measuring gaze throughout this process. The results of the measurements showed that while experienced teachers did place emphasis on students they felt they needed to observe, they nonetheless looked at all the students. The novice teachers, however, spent a longer time observing only one student who drew their attention by failing to look at a teacher or for some other reason, and were unable to distribute their gaze to the students overall. Also, when students performed behaviors such as standing up and walking or making noise, the novice teachers tended to continue looking at that area even after the event, and to spend less time observing other areas. It became clear that while experienced teachers understood noteworthy events occurring in the classroom, their attention was not dominated by them, and they observed the totality of the events. Also, other studies have investigated differences in the gazes of experienced teachers due to cultural differences between Hong Kong and the UK, as well as the characteristics of the gazes of learners when reading textbooks and learning materials (Kang, 2014; Liu, 2014; McIntyre, Jarodzka, & Klassen, 2017). This technique has spread widely and become highly useful in pedagogical studies.

1.2. Challenges of figure education

At present, Japanese arithmetic classes are divided into four areas: numbers and calculations, quantities and measurements, geometrical figures, and mathematical relations. The domain of geometrical figures is just as significant as numbers and calculations. However, students tend to differ greatly in terms of their proficiency with figures, and it has proven difficult to provide individualized guidance (Suzuki, 1980). One of the difficulties is the necessity of mentally envisioning the movement and transformation of figures. Figure problems, unlike calculation problems, are not solved on paper, and it is necessary to mentally flip, turn, raise, lower, and spin figures. As it is difficult for students themselves to express the intermediary solution and thinking processes involved in their solution attempts, it has been difficult for teachers to determine which points students lack understanding of. Also, the fact that solutions often come in a flash of insight presents a further difficulty. Unlike calculation and word problems, which tend to be solved in ordered steps, flashes of insight often determine where to draw additional lines and so on, making it difficult for students to explain how they have arrived at their solutions, and teachers likewise have difficulty grasping this information. Also, because the thinking process is not visible, even when advice is offered, it is difficult to determine whether it has proven useful, and thus there is a need for a method of comprehending the solution and instruction processes.

1.3. Purpose of the study

In this study, a one-on-one instructional situation using figure problems was postulated, and an experiment was conducted wherein the eye movements of two people, one in a student role and the other in a teacher role, were measured. As the students worked on the tasks, they could request hints as necessary, and as the teachers observed the students' progress, they could provide hints as necessary. The purpose of this study was to elucidate the general characteristics of the gazes of students and teachers, and to consider the differences in the characteristics of teachers' gazes when requested by students to provide hints and when providing hints spontaneously.

2. Method

2.1. Participants

The experiment was conducted in pairs, with a total of 22 healthy university students (7 males, 15 females; age 20.6±1.7). Prior to the experiment, the experimental data collection methods, the uses of the experimental data, and so on, approved by the research ethics committee of the university where the experiment was conducted, were explained to participants and written consent was obtained.

2.2. Apparatus

Tobii pro glasses2 (Tobii Technology K.K.) were used. Measurements are taken simply by wearing them as regular glasses are worn. The apparatus is equipped with a camera that records footage of the participant's visual field and eye movements, and data consisting of a video showing the participant's point of gaze atop footage of the visual field can be obtained.

2.3. Experimental task

Tangrams (puzzles in which seven pieces are arranged into a set shape) were used for the experimental task. Three trials were conducted, each consisting of one problem (Okamoto, 2008). The time restriction of each trial was 90 seconds, and a rest period of 60 seconds was established between trials (Figure 1). In the experiment, the teacher and student participants formed pairs. The students' role was to work on the tangrams, while the teachers' role was to observe the students working on the tangrams and provide hints. In this experiment, a hint consisted of the teacher showing the student where to place one piece. Hints were provided using tangrams specifically for hints that were placed between the students and the teachers, and teachers were able to refer to an answer key at any time (Figure 2). With the condition that the set shape was to be completed within the time limit of 90 seconds, hints were provided when the student or

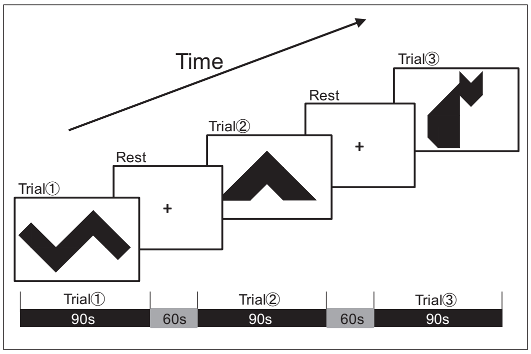

Figure 1: Experimental task

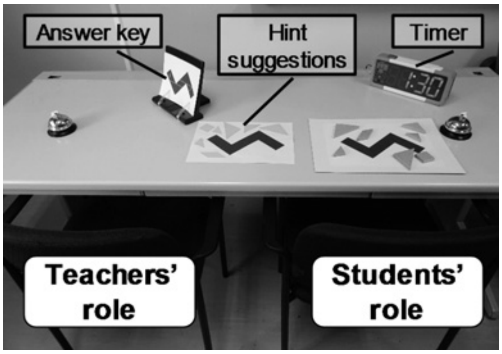

Figure 2: Configuration of experimental environment

teacher rang a nearby bell upon either party's determination that a hint was needed. When teachers were the ones to provide hints, within the time limit, either party could request a hint or suggest providing a hint at any time. When a student rang the bell and requested a hint, this was referred to as a "student-requested" hint, and when a teacher rang the bell and suggested providing a hint, this was referred to as a "teacher-suggested" hint. The maximum number of hints per trial was seven, owing to the fact that a tangram has seven pieces. To make both parties aware of the time limit, the remaining time was shown on a timer.

3. Results

3.1. Behavior data

(1) Time needed and number of hints

Figure 3 shows the average time needed by all pairs (mean±S.E.) and the total number of hints. The time limit per trial was 90 seconds, but because four groups were unable to finish within the time limit (one trial each), the time needed for these trials was deemed to be 90 seconds in calculating the averages. The number of hints was divided into student-requested and teacher-suggested.

As shown in Figure 3, the total number of student-requested hints was 25 and the total number of teacher-suggested hints was 22, for a total of 47 hints. The order of the trials by amount of time needed, from shortest to longest, was ①, ③, ②. The order of the trials by total number of hints, from lower to higher, was also ①, ③, ②, showing a correspondence between the amount of time needed and the number of hints. With regard to the number of hints by type, in all trials, the difference between the number of student-requested and teacher-suggested hints was one.

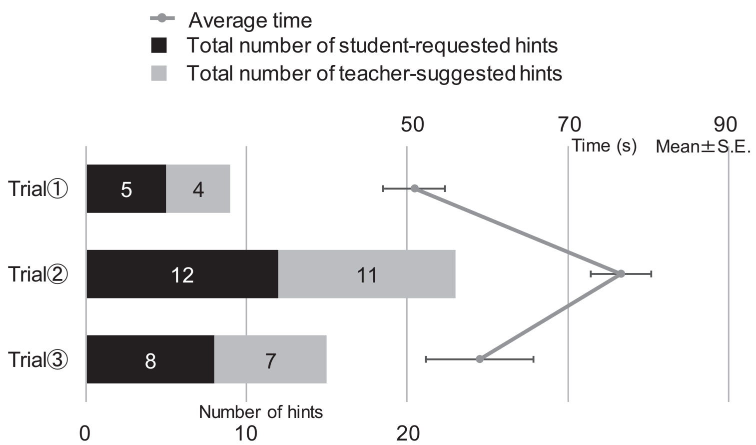

Figure 3: Average time needed (seconds) and total number of hints

(2) Pieces placed following hints

To analyze the usefulness of hints, it was determined whether the piece after the hint was placed correctly. The results indicate that all 47 pieces placed after hints were in the correct position. Also, the average time needed for a piece to be placed after a hint was calculated separately for student-requested and

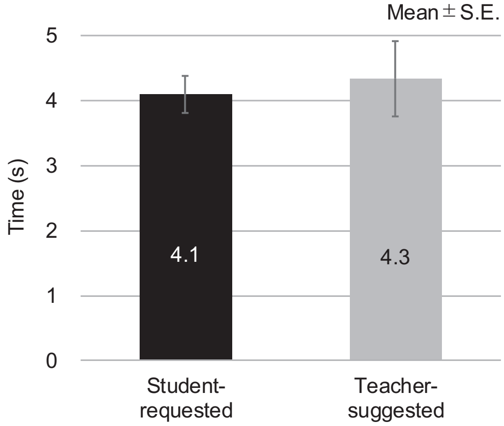

Figure 4: Average time to place a piece after a hint

teacher-suggested hints (Figure4). In both cases, the time was approximately four seconds, with no significant difference ($t(30)=0.38$, n.s.).

3.2. Eye movement data

(1) Distribution of gaze

Gaze areas were established, and gaze measurement data were used to calculate which area participants looked at and for how long. For students, the following three gaze areas were established: (1) work area at hand: the area where the student was personally working on the problem, (2) hint suggestions: tangrams and suggestion sheets for providing hints, and (3) other: areas other than the above, such as the timer, bell, and so on. For teachers, the following four gaze areas were established: (1) student's progress: the student's tangram and work area at hand, (2) answer key: the answer key placed before the teacher, (3) hint suggestions: tangrams and suggestion sheets for providing hints, and (4) other: areas other than the above, such as the timer, bell, and so on.

Figures 5 and 6 are graphs showing the average gaze proportion of all 11 students and teachers

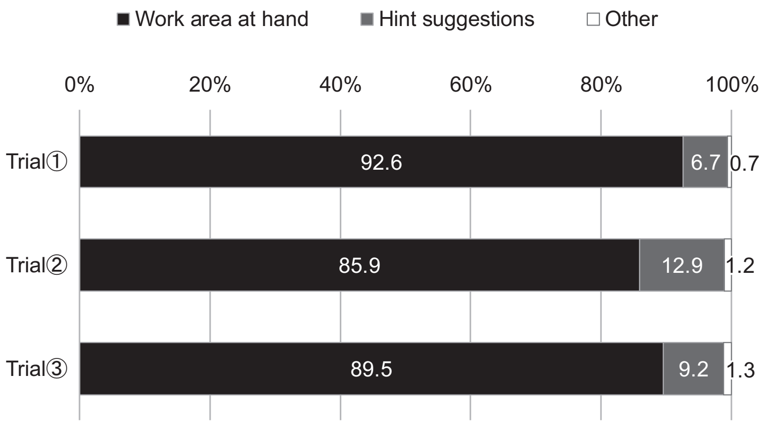

Figure 5: Students' gaze distribution

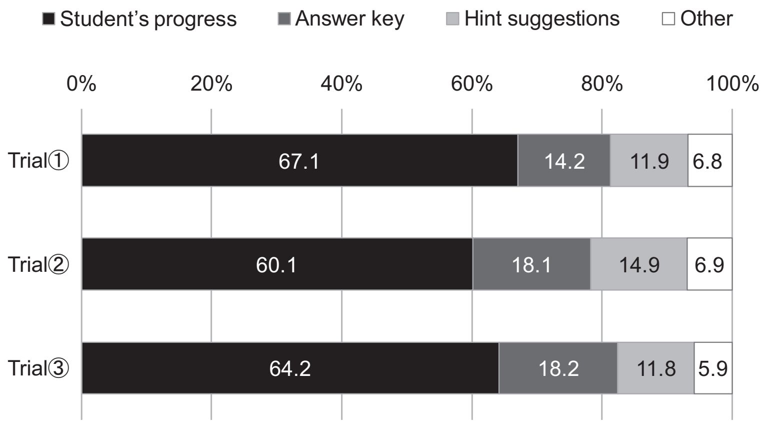

Figure 6: Teachers' gaze distribution

calculated based on their gaze times. On the basis of Figure 5, it is apparent that in all trials, the proportion of time students spent looking at the work area at hand was more than 85%, the largest of any gaze area. Hint suggestions were around 10%. The order of the trials from the lowest proportion of time spent looking at the hint suggestion to the highest was ①, ③, ②. On the basis of Figure 6, it is apparent that in all trials, teachers shared the characteristic of spending the highest proportion of time observing students' progress, around 60% of the time. Also, the results of all trials uniformly show that the order of the focus areas from the highest proportion of time to the lowest was as follows: student's progress, answer key, hint suggestions. A comparison of trials shows that a higher proportion of time was spent looking at hint suggestions in Trial ② than in other trials. Also, in terms of the proportion of time spent looking at students' progress, the area with the highest gaze proportion in all trials was in the order of ①, ③, ②.

(2) Teachers' hint provision process and gaze characteristics

Let us analyze the hint provision process, that is, the time between the ringing of the bell and the

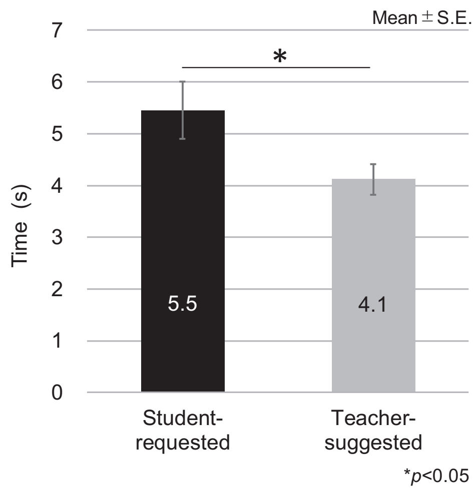

Figure 7: Time of the hint provision process

provision of the hint. Figure 7 shows the results of measuring the time needed for the hint provision process of all 47 hints and separately calculating the average times for student-requested and teacher-suggested hints. It is apparent that more time was needed to provide student-requested hints ($t(45)=2.05$, $p<0.05$).

Figure 8 presents the average gaze times of the four gaze areas in the hint provision process, and Figure 9 shows the average number of times participants looked at each area for student-requested and teacher-suggested hints. Figure 8 shows that gaze time was longer for the answer key when the hint was student-requested (t=2.774, df=45, $p<0.05$). Also, Figure 9 shows that the number of times teachers looked at the answer key and hint suggestions tended to be higher for student-requested hints (Answer key: $t(45)=2.02$, $p<0.05$, Hint suggestions: $t(45)=1.90$, $p=0.063$).

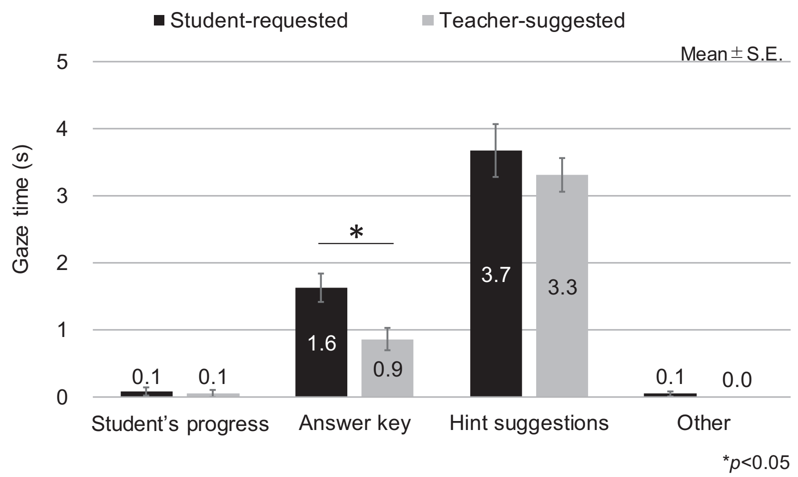

Figure 8: Gaze time by area during the hint provision process

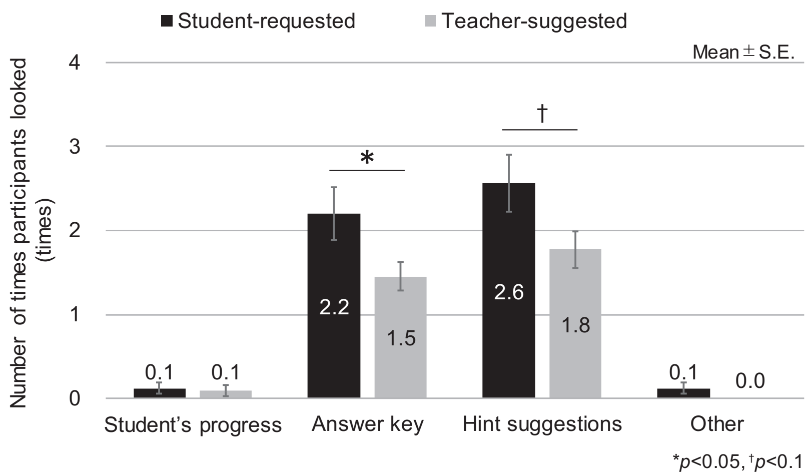

Figure 9: Number of times participants looked at each area during the hint provision process

4. Discussion

First, since the behavior data demonstrate that the order of the trials was ①, ③, ② in terms of both the amount of time needed from shortest to longest and the total number of hints, it seems probable that the order of the trials by the degree of difficulty sensed by students would be likewise. Also, the number of student-requested and teacher-suggested hints differed by just one in all trials, indicating no marked tendency in either direction. It seems unlikely that the degree of difficulty sensed by students was influenced by differences in the type of hint. Also, regardless of whether it was student-requested or teacher-suggested, students always correctly placed the piece following a hint. It is conjectured that the hints functioned effectively, helping the students make progress in solving the problems. The time needed to place the piece after a hint was found to be approximately four seconds for both student-requested and teacher-suggested hints, with no difference between the two. Thus, it seems that placement of the next piece proceeded smoothly subsequent to a hint.

Next, with regard to the distribution of students' gazes demonstrated by eye movement data, in all trials, the proportion of time spent looking at the work area at hand was more than 85%, the largest proportion of any gaze area. It can be said that students spent most of the time looking at the work area at hand. Distribution of gaze to hint suggestions was around 10%, and in terms of the lowest to highest distribution of gaze to this area, the order of the trials was ①, ③, ②, the same as the order of the trials in terms of lowest to highest number of total hints. It can be said that an increase in the number of hints led to an increase in the proportion of gaze distribution to hint suggestions.

In all trials, the order of the gaze areas was, from the lowest proportion of teachers' gaze distribution to the highest, students' progress, the answer key, and hint suggestions. The proportion of gaze distribution to students' progress was the highest, approximately 60%, indicating that approximately 40% of the time, teachers were not looking at students' progress. A comparison between the trials shows that in Trial ②, in which the number of hints was the highest, the proportion was higher for hint suggestions than in other trials. Also, from the highest to the lowest proportion of gaze distribution to students' progress, the order of the trials was ①, ③, ②, indicating that when the number of hints was higher, the proportion of time spent looking at students' progress decreased. While the order of the gaze proportions by area did not change between trials, it may be said that where students tended to sense a higher degree of difficulty, when the number of hints was higher, the proportion of time spent looking at students' progress decreased.

Also, the hint provision process from the ringing of the bell to the provision of the hint took longer for student-requested hints than teacher-suggested hints. Based on the results of focus time for each area, it can be said that the cause was the length of time spent looking at the answer key. As hints were requested at a time that was unexpected for the party giving the advice, it is conjectured that following the ringing of the bell, teachers took time to review the answer key and think about the hint. Also, because of the high number of times the answer key and hint suggestions were looked at, it seems to have taken time to look at the two and confirm the hint to be provided.

To apply the above information to actual learning and instructional situations, it can be said that when students are working on problems, their gazes stay focused mostly there, whereas teachers have numerous things to think about and do not focus their gazes only on observing learners. The answer key of the experiment in this study can be said to correspond to the answer keys and instructional guides teachers have at hand in classrooms, or alternately to the knowledge and answer keys they hold in their minds, the information to which teachers refer as they observe learners. However, it is conjectured that in some cases, when teachers give advice (a hint) at a student's request, they think about the hint following the request, requiring more time than when they make the suggestion themselves. Ordinarily, it is necessary for them to think of effective advice as they observe learners, and to this end it seems that knowledge and experience encompassing instructional methods, common mistakes, and so on play an important role.

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教師の指導過程と生徒の問題解決過程における視線移動の特徴
―図形問題の場合―

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指導者の指導過程，学習者の学習過程における思考状況を適切にとらえることは，効果的な指導のために重要な課題である。そのため，教育学研究においては，それらを把握する手法として，ビデオ録画やプロトコル取得など，複数が検討されてきた。近年では，より客観的なデータが求められていることからも，従来の手法に加えて，生理学データの有用性が議論され始めており，生理学データの中でも，どこを見たのかを計測・記録できる視線移動データは，有用性の高いデータとなる可能性がある。視線移動データは，本人も無意識的な視線行動を検出でき，また，どこを見たのかという分かりやすく了解性の高いデータであることに利点がある。算数・数学科において，図形問題の指導は，計算問題に比べて紙面上に解決過程が残りづらく，思考過程の把握が難しいことから，指導の困難性が指摘されてきたが，視線移動計測は思考過程を捉える有用な手法となることが期待できる。

そこで，本研究では，図形問題を用いた一対一の指導場面を想定し，生徒役と教師役を設定した両者の視線移動計測実験を行った。生徒役は，課題に取り組みながら，必要に応じてヒントをもらうこととし，教師役は，生徒役の遂行状況を観察しながら，必要に応じてヒントを提示することとした。ヒントは生徒役が要求したときと，教師役が提案したいときに教師役が提示し，教師役は，模範解答を常時確認できるようにした。生徒役と教師役それぞれの全体的な視線特徴を明らかにするとともに，生徒役から求められて行うヒント提示と，教師役が自発的に行うヒント提示の視線特徴の違いを検討することを目的とした。実験の結果，生徒役は課題遂行時，自身の手元を注視する時間割合が約９割であった一方，教師役は生徒役の課題遂行状況を注視していた時間割合は６割台にとどまった。残りの約４割の時間は，模範解答やヒント提示物，タイマーなどを注視していた。また，生徒役から求められて行うヒント提示と，教師役が自発的に行うヒント提示では，前者の方がヒント提示に時間を要し，ヒントを求められた後に「模範解答」を見る回数が多い結果となった。学習者からヒントを求められることを意図していなかったため，ヒントを求められてからその内容を考えていたことが推察された。

キーワード：指導，問題解決，視線移動，図形問題

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