Cognitive processes of high intelligence student with autism spectrum disorder in understanding mathematical problems

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Abstract. The purpose of this study is to describe the cognition processes of an ASD student with a high intelligence quotient (IQ) in understanding mathematical problems. The processes of cognition being studied are the process of receiving, storing, recalling and processing information. The subject of this research is a high IQ autism spectrum disorder (ASD) student. Data was gathered from task-based interviews. The results of this research indicate that in the process of receiving information, the ASD characteristics of the subject were still very visible, such as reading with a flat expression, interspersed laughing and smiling to themselves, repeating certain words and muttering speaking an unclear sentence. In the process of storing and recalling information, the subject: (1) stored and recalled information in the problem in three visual representation forms: images, verbal language and arithmetic symbols, (2) stored and recalled important information, and (3) recalled information that has been stored in his long-term memory by linking it to the concepts in the problems. In processing information, the subject: (1) mentioned the information and the question in the problems, (3) understood the meaning of the symbol in the problems, (4) understood the adequacy of the information in the problems, and (5) was able to reduce the information in the problems.

1. Introduction

Mathematical learning plays a big role in improving reasoning, logical thinking, critical thinking, and creative and communicative abilities. In an attempt to develop those abilities in mathematical learning, students are given more challenges in the form of problems to be solved. Before solving the problems, students are indeed expected to be able to understand the problems first. Comprehensive understanding of context, concept and symbol in mathematical problems will ease students in setting up their solution. Students who have difficulties understanding mathematical problems have influenced the problem solving process [1].

There is a lot of research on students’ abilities in solving mathematical problems, yet there is still limited in-depth research on cognitive process as students try to solve mathematical problems, especially with autism spectrum disorder (ASD) students. Naturally, a slightly different intervention will be needed for students with ASD [2]. Meanwhile, the prevalence of children with ASD is increasing each year. In Indonesia, there are 1.2 children for every 1000 who are diagnosed with ASD [3]. There are 5.1 children in every 1000 children experience similar disorder in Western Australia [4].

Research on mathematics education is commonly applied under the normal students but it is rarely conducted under abnormal students such as students with ASD. For this reason, this study aims to reveal cognition process of students with ASD who have high intelligence level in understanding mathematical problems. The results of this study can be used as an input for mathematics teachers especially in teaching students with ASD in inclusive schools.
1.1 Understanding mathematical problems

The process of understanding a problem is the first part of solving mathematical problems. This process becomes a very important part of one's efforts to solve mathematical problems. Polya put the process of understanding problem as the first of four steps in his theory, followed by planing, implementing the solution plan and re-checking the solution [5]. A student who is able to understand a mathematical problem well will be able to set a plan or strategy easily.

The understanding of a mathematical problem is indeed related to the understanding of context, concept and symbol that appear in the mathematical problem. Naturally, a comprehensive understanding of sentences in mathematical problems is needed, especially mathematical word problems. When understanding a mathematical problem, the concept that exists in mathematical problem will be associated with schemes that have been stored in long-term memory. These schemes are being recalled and associated in order to set a solving plan accurately.

1.2 Cognition processes in understanding a mathematical problem

Cognitive processing is a mental process that exists in the human brain to process some information [6]. Cognition is not just a process but a mental process. Cognition refers to a mental process through external and internal input, being transformed, reduced, interpreted, stored, recalled, and used. Therefore, mental activities include various functions such as perception, attention, memory coding, retention, and recalling, decision making, reasoning, problem solving, describing, planning and executing [7].

Understanding a problem is a mental activity in which someone perceives, memorizes, and thinks about information in the problem [8]. Cognition processes involves the acquisition, storage, transformation, and use of knowledge [9]. Therefore, in this research, cognitive processing in understanding problems consists of four processes, namely the process of receiving information, storing information, recalling information and processing information.

1.3 Mathematical learning of a student with ASD

Mathematical learning aims to develop students’ logical thinking ability. In mathematical learning, students are given many opportunities to solve various problems. High-quality problems give students the chance to strengthen and broaden their knowledge and stimulate new learning. Most mathematical concepts can be introduced through experience-based problems which students are already familiar with, which comes from students’ real life experiences or from mathematical context. Mathematical problem solving is related to several things including the ability to understand problems, awareness of problems or problem-solving strategies [10].

Without question, communication between students and teachers, as well as communication among students is needed in mathematical learning. This communication will give a positive impact for students in improving their mathematical communication ability. Communicating during the learning process will not be a problem for normal students; however, it will be difficult for students with a disruption of communication and social interaction, such as students with autism. Autistic children who have IQ levels above 90, which is known as high-functioning autism spectrum disorder, have the ability to solve mathematical problem well, even though in the process of solving the problem some autism characteristics, such as smiling to themselves, reluctance in making eye contact with other people, repetitive and mumbled utterances, appear [11].

1.4 Student with ASD in an inclusive school in Indonesia

There are two kinds of schools in Indonesia, public and private schools. Both public and private schools can serve as an inclusive school. An inclusive school accepts students with various special needs, including students autism, Down’s syndrome, cerebral palsy, deafness, and many other disorders. Inclusive schools provide special assistant teachers for students with special needs who have competence in special education. Their experience in accompanying children with special needs will enhance their competence in inclusive education field in addition to joining special training on handling children with special needs [12].
The purpose of inclusive education is to enable children with special needs to get the same education as children without special needs [13]. Children with special needs can socially interact with normal children so that the disruption they have experienced will be reduced. Inclusive schools are already available in each regency in Indonesia. The government gives full support in developing inclusive schools through facilities compliance.

2. Methodology
The main purpose of this research is to reveal the cognition processes of a high-intelligence student with ASD in understanding mathematical problems. The cognition processes involved receiving information, storing and recalling information, and processing information.

2.1 Participant of the research
The subject in this research was a high school student with ASD who had an above-average IQ score of 115. The subject was 16 years old and in the 10th grade in a private inclusive school. The subject was diagnosed with ASD at age 3 years old and had been doing therapy since from age 6 years until now to control his emotions. At the moment, the subject is no longer experiencing tantrums and is still able to communicate even though he still has no initiative to initiate communication with others.

2.2 Ethics/permissions
The researchers obtained permission from the Ministry of Education and Culture and relevant schools. Pseudonyms have been used to protect the identities of the participants who were free to withdraw from the research without fear or prejudice at any time.

2.3 Setting and design of the research
The research took place in a private high school in East Java Province in Indonesia. The subject attended a private high school in an inclusive education setting. The school was located in an industrial area of the city. At the school, a certified educator provided support services for students with ASD.

The research approach was done in a flexible and evolving style in accordance with the circumstances in the field. Adjustments were made for the factors that affect the results of the study. The results of the study cannot be generalized, but only reflect actual phenomena in the field according to the research objectives. This research focused on a student with high functioning autism spectrum disorder, so this research is a case study. The approach is categorized as qualitative, while this type of research is descriptive explorative research [14].

The qualitative data on the general form of words was derived from observations, interviews or documents. Qualitative data has advantages compared with quantitative data; for example, qualitative data is richer in terms of descriptions and explanations [15].

2.4 Instruments and its validation
In accordance with the type of the research (qualitative), the main instrument in this research was the researcher’s observations, while the auxiliary instrument was in the form of mathematical problem test instruments and instrument-guided interviews. As a main instrument, the researchers acted as a planners, collectors, analyzers, interpreters and reporters of the research results. Thus, the researchers have to be objective, responsive and neutral.

The materials in the problems was developed based on curriculum applicable at the high school level. The mathematical problem test instrument was used to collect data about the cognitive processes undertaken by the subject in understanding mathematical problems. The responses written or disclosed by the subject in each problem understanding step were used as a guide to analyze the processes of cognition conducted by the subject.

Mathematical problem test instruments were processed by experts through content validation to validate the construction of problems, materials and language in the problems. The validators were two
mathematics teachers and two mathematics specialists from a university. The topic in the problems is arithmetic sequence.

2.5 Data collection and analysis procedures

The data collection in the research was conducted consecutively, one at a time. The data collection was done by using task-based interviews with a think-aloud method. The subject of this research worked on mathematics problems by writing answers on the answer sheet provided and revealing what he was thinking at that time by narrating out loud. If the subject did not reveal his thought processes, the researchers would ask probing open-ended questions to elicit a response. All activities of the subject at the time of understanding mathematical problems were recorded with a video recorder. The think-aloud method can be effectively applied to gain the data of a qualitative research. In this research, the participant has to speak aloud any words that they are thinking when they complete the task. Think-aloud research methods have a strong theoretical basis with a valid source of data about what is in participant’s mind during the language-based activities [16].

Analysis of the data used the answer sheet of subject, the transcripts from the video recording and interpretations of the subject’s behaviors while he engaged with the problems. This research used the second problem as time triangulation to data validation. The valid data of cognition processes was categorized into three categories: receiving, storing and recalling, and processing information.

Furthermore, the data were used to answer the research question.

3. Results

This research revealed the cognition processes of subject in understanding a mathematical problem. The cognition processes involved receiving, storing and recalling, and processing information.

3.1 Receiving information

The subject received information by reading the problem aloud with a soft voice, used a different tone for certain words, had a flat facial expression, at a certain points interspersed with laughter and smile to themselves, repeated some certain words (repetition) and mumbled unclear sentences.

3.2 Storing and recalling information

To solve the problem, the subject tended to focus on information which is considered most important. Information which is considered most important in a problem includes pictures and some information that is in the form of sentences given in the problem. This interview transcript represents the description:

| Researcher | In Fian’s opinion, which information is the most important that can be used to solve this problem? |
|------------|------------------------------------------------------------------------------------------------------------------|
| Subject    | The most important information in this problem is the number or the matches.                                      |
| Researcher | Is there any other important information in that problem?                                                        |
| Subject    | The most important one is the picture (pointing at the picture in the problem)                                   |
| Researcher | Next to the picture, is there anything else?                                                                      |
| Subject    | This (pointing at phrases in the problem) the writing of 3 pieces of matches, first level, 9, second level added to level 3. |
| Researcher | Is there anything else?                                                                                           |
| Subject    | Nothing.                                                                                                          |
| Researcher | Fian said that the most important thing is the number of matches, the picture and the written numbers in the problem, isn’t it? Why are those important? |
| Subject    | So that we can answer the question in the problem.                                                                 |
The subject stored most of information in the problem and recalled that information in three forms of visual representation, which are pictorial, verbal language, and symbol representations, which can be seen in pictures below:

![Figure 1. Pictorial, verbal language, and symbol representations](image)

Schemes which are stored in long-term memory are being recalled and connected to some concepts in the problem. This interview transcript represents the description:

| Researcher         | Fian, have you ever solved this kind of problem? |
|--------------------|--------------------------------------------------|
| Subject            | Yes, yes, I have.                                |
| Researcher         | Where?                                           |
| Subject            | At school.                                       |
| Researcher         | In what grade?                                   |
| Subject            | 9th grade (mumbling to himself and the words he said are not clear). |
| Researcher         | This problem is related with what concept?      |
| Subject            | Ehmm.                                           |
| Researcher         | I mean, this problem is related with what kind of topics on Mathematics lesson? |
| Subject            | Number sequence.                                |
| Researcher         | Which part that connected to sequence?          |
| Subject            | In this problem, 3, 9, and 18. Those are the the sequence. |
| Researcher         | What else?                                       |
| Subject            | Pattern of number.                              |

### 3.3 Processing information

The subject understood well what was given in the problem because the subject had revealed most information known in the problem. The reason subject believed that the information was what was known in the problem was because it was clearly visible in the problem. This interview transcript represents the description:

| Researcher         | Then, what is known in the problem?             |
|--------------------|--------------------------------------------------|
| Subject            | It is about the number of matches, the matches are arranged, this one in 3, this one in 9 and this one 18 (pointing at picture in the problem just like picture 4.12) |
| Researcher         | Is there anything else that you don’t understand in the problem? |
| Subject            | Nothing.                                        |
| Researcher         | In your opinion, why do you think that it is what is known? |
Subject: It determines the order.
Researcher: Oh. When you read the problem, how can you be sure that it is what is known?
Subject: Because it is clearly visible here (smiling while pointing picture in the problem sheet, then looking at the researcher)
Researcher: Oh...where is it clearly visible?
Subject: Over here (pointing to the sentence in the problem, then picture in the problem).
Researcher: Oh...where is it?
Subject: In the picture.

The subject understood well what was being questioned in the problem because subjects had mentioned appropriately what was being questioned in the problem. The reason the subject believed that it was the item that was being questioned in the problem because it was relevant to what was known in the problem. This interview transcript represents the description:

Researcher: Then, what is being asked in that problem?
Subject: How many matches which are needed to arrange a triangle with 5th level and 10th level.
Researcher: Only that one?
Subject: And n level.
Researcher: Okay Fian, is there anything else that is being questioned?
Subject: That’s all.
Researcher: Why do you think that this one is what is being questioned?
Subject: Because what is questioned is level 5, 10 and n.
Researcher: Why it is not the others?
Subject: The others are not relevant with this one (pointing problem while smiling).
Researcher: So, what is your reason you choose this one as what is being questioned?
Subject: Because it is on the problem.

The subject could understand well the meaning of symbol or notation in the problem because subject could reveal appropriately the meaning of that symbol. This interview transcript represents the description:

Researcher: What is the meaning of n level, Fian?
Subject: n level is n level, it means that whatever n is inputted, they can be inputted.
Researcher: So if later the answer is found for n level, what is likely the answer to that?
Subject: In the form of n.
Researcher: What do you mean with n?
Subject: Well, it can be counted in every level.
Researcher: Is it possible that n is a negative number?
Subject: If... if n is in many level it’s impossible for it to be a negative number.
Researcher: Is it possible n is fraction?
Subject: Level is never fraction.
Researcher: What is the biggest n number?
Subject: Well, infinite.
The subject could understand well the adequacy of information given in the problem with a reason that through this information, it could be used to solve the problem. This interview transcript represents the description:

| Researcher | In Fian’s opinion, is the information given in the problem enough to solve that problem? |
|------------|-----------------------------------------------------------------------------------------|
| Subject    | What do you mean?                                                                         |
| Researcher | Do you need any other information to solve that problem?                                  |
| Subject    | Oh, no.                                                                                  |
| Researcher | No more information needed?                                                               |
| Subject    | No, nothing.                                                                             |
| Researcher | So is it enough?                                                                         |
| Subject    | Yes.                                                                                     |
| Researcher | Why enough?                                                                               |
| Subject    | Because it is stated clearly in the problem (pointing at the sentence in the problem) and in this picture (pointing at the picture in the problem). |

The subject understood that if some crucial information was omitted, then the problem could not be solved. This interview transcript represents the description:

| Researcher | For example, what is known is only picture level 1, is it enough to solve the problem (covering triangle picture level 2 and 3 by hand)? |
|------------|-----------------------------------------------------------------------------------------------------------------------------------|
| Subject    | No.                                                                                                                              |
| Researcher | Why can’t it be done if the known one is only level 1?                                                                            |
| Subject    | Ehmm, because I don’t know which pattern to continue                                                                              |
| Researcher | Which means?                                                                                                                      |
| Subject    | The pattern cannot be seen.                                                                                                        |

The subject was able to reduce information in the problem to a minimum without reducing the adequacy of problem in order to be solved. This interview transcript represents the description:

| Researcher | If it’s only level 2 that is known, how (covering the picture of triangle arrangement level 3 by hand)? |
|------------|-----------------------------------------------------------------------------------------------------|
| Subject    | Clear.                                                                                               |
| Researcher | So, if it’s only level 2 that is known, still can be done (covering the picture of triangle arrangement level 3 by hand)? |
| Subject    | Yes, it can.                                                                                         |
| Researcher | What is the reason it still can be done?                                                            |
| Subject    | Because the pattern still can be seen.                                                               |
To make it easier to understand the cognition process, it is described in the following scheme.

Figure 2. Schema of the cognition process of high intelligence student with ASD in understanding mathematical problem

4. Discussion
4.1 Receiving information
The characteristics of a student with ASD appear when receiving information. This finding is in accordance with the research conducted by Randall et al. [17]. This finding can be used as a consideration for teachers to provide appropriate interventions for students with ASD. Teachers can provide media in the form of images as a communication aid for ASD students who are visual learners. In the learning process, there should be more focus on communication with peers and avoiding leaving children with ASD alone in the classroom. Communication with peers will help reduce the disruption of
their social interactions and communication. This is in accordance with the research conducted by Carter et al. [18].

4.2 Storing and recalling information

The subject is more focused on important information in the problems that he used to solve the problems. This finding demonstrates that the subject has the right attention ability to some information that enters his focus. Thus, through appropriate intervention, the attention ability of ASD students can be improved, as shown in research conducted by Patten and Watson [19].

The subject stores most of the information in the problems and recalls in three forms of visual representation (images, verbal language, and symbols). Schemes stored in long-term memory are recalled and associated with several concepts in the problem. This finding shows that ASD students can store a lot of information in short- and long-term memory. ASD students can also recall the memory even in several forms. These abilities do not necessarily belong to non-ASD children. The findings in this research are different from the research conducted by Williams, Goldstein, and Minshew [20]. The research subject conducted by William involved 38 high-functioning students with ASD. This study showed that the memory retained by the subjects was relatively poor for complex visual and verbal information.

4.3 Processing information

The subject understands the sentence in the problems well, is able to distinguish what is known and asked in the problems, and is able to understand symbols or notations in the problems. This finding was similar to that reported by Luculano et al. [21] but inconsistent with the one reported by Bae, Chiang, and Hickson [22].

The subject can understand well the adequacy of the information in the problems. The subject is able to reduce the information in the problems to a minimum without reducing the adequacy of the problems to be solved. These findings indicate that an ASD student who has received right teaching will improve their ability in reading comprehension. This is consistent with the research conducted by Roux, Dion, Barrette, Dupéré and Fuchs [23].

5. Conclusion

To concluded, this research shows that characteristics of ASD children still occurred, such as reading with flat expression, laughing and smiling to themselves, repeating certain words, and mumbling unclear sentences as they are receiving information.

During the process of storing and recalling information, the subject tended to focus on information that considered as the most important in mathematical word problems with the reason of that information could be used to solve the problems. Subject stored most information in that mathematical problem and recalled them in three forms of visual representations, specifically pictorial, verbal language, and symbol. Schemes which have been stored in long-term memory were recalled and connected to some concepts in the mathematical problem.

In processing information, the subject understood well what was already known in the mathematical problem because they had revealed it. The reason the subject believed that the information was what was known in the problem was because it was clearly visible in the problem. The subject understood well on what was asked in the problem because they had mentioned precisely what was questioned on the problem. The reason the subject believed that the information was what was questioned in the problem was because it was relevant with what was known. Subjects could understand the meaning of symbols or notations on the problem well because they could reveal the meaning of that symbol precisely. Subjects could understand the adequacy of information in the problem with the reason that the information could be used to solve the problem. The subject understood that when some crucial information in the problem was omitted, the problem could not be solved. The subject could reduce information in the problem as minimally as possible without reducing the adequacy of the problem in order to be solved.
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