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Student-Teacher Level of Statistical Reasoning Ability Reviewed by Apos Theory (Action, Process, Object, Schema)

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ABSTRACT

In learning statistics, there is the term statistical reasoning. Statistical reasoning arises because of the opinion that learning statistics using a traditional approach does not lead students to have statistical reasoning abilities or to think statistically. There are four statistical reasoning levels: idiosyncratic, transitional, quantitative, and analytical. Student-teachers must understand fundamental statistical concepts more deeply to develop statistical reasoning abilities. The mental construction of a statistical concept can be analyzed using APOS (Action, Process, Object, Schema) theory. Through the APOS theory, researchers can determine individual understanding of statistical concepts that cause individuals to reason or draw reasonable conclusions based on the statistical information obtained. This study aims to analyze the interrelationships and make conjectures regarding the level of statistical reasoning ability based on the APOS theory. The research subjects are. 19 informants. The research results obtained four conjectures, namely. Students at the idiosyncratic level are in the action stage; students at the transitional stage are in the action, process, or object stage; students at the quantitative stage are in the process or object stage; lastly, students at the analytical are in the schema stage.

Keywords: APOS theory; mathematics education; statistical reasoning

INTRODUCTION

In learning statistics, there is the term statistical reasoning. Statistical reasoning arises because of the opinion that learning statistics using a traditional approach does not lead students to have statistical reasoning abilities or to think statistically. The traditional learning approach focuses on competencies, procedures, and calculations (Ben-Zvi & Garfield, 2004). Garfield & Gal (1999) define statistical reasoning as how individuals think about statistical ideas and make statistical information acceptable (make sense). Statistical reasoning combines ideas about data and probability that lead to inferences and interpretation of statistical results. Statistical reasoning is based on a conceptual understanding of essential topics, such as distribution, data concentration measures, data dispersion, association, uncertainty, randomness, and sampling.

Based on this understanding of statistical reasoning, students need statistical reasoning abilities because procedural capabilities are insufficient. With statistical reasoning skills, students can utilize statistics for needs in various fields, be it education and psychology, agriculture, science, social, and even economics, as a provision for living life in the future. Especially nowadays, the digital revolution makes statistical reasoning much needed because the information is always in the form of data. We often see the data presented in various forms, including images, dynamic images, innovative and interactive visualizations, numbers, and graphs. Analyzing data is crucial in multiple lifelines, including business, industry, social welfare, education, and government (Burrill & Ben-Zvi, 2019), which students will face in the future. The need for statistics causes statistical application techniques to increase occasionally. Several universities worldwide require students to take at least one Statistics course as a graduation requirement (Onwuegbuzie & Wilson, 2003).

Teachers can evaluate Students' statistical reasoning abilities by considering four statistical construction processes: describing, organizing, representing, and analyzing and interpreting data (Jones et al., 2004). In addition to the statistical construction process, there are four levels of statistical reasoning: idiosyncratic, transitional, quantitative, and analytical (Jones et al., 2000, 2001; Mooney, 2002). Student reasoning at the idiosyncratic level is tied to a reason unrelated to the data provided and often focuses on personal experience or subjective beliefs. Students reasoning at this level may be distracted or misled by irrelevant aspects of a given statistical problem. Students begin to use quantitative reasoning at the transitional level but are inconsistent in using this reasoning. Student reasoning at this Level can solve statistical problems in a relevant way but generally only focus on one aspect of the problem situation. Students reasoning is consistently quantitative at the quantitative level, in the sense that students can identify statistical ideas from problem situations and are not distracted or misled by irrelevant aspects. However, quantitative-level students cannot integrate relevant ideas when working on the problem. At the level of analytical, students reason by connecting various elements of the statistical problems encountered. Students reasoning at this level can integrate relevant aspects of a problem into meaningful structures (for example, creating multiple views of data or making plausible predictions).

The results of a preliminary study conducted by researchers on 60 students at a university in Bandung show that more than 50% of students are still at the idiosyncratic Level. The rest are at the quantitative and transitional levels, while only one student is at the analytical Level.

Researchers have researched statistical reasoning. Olani et al. (2011) examined changes in statistical reasoning, self-efficacy, and student value beliefs after learning statistics using the Guidelines for Assessment and Instruction in Statistics Education (GAISE). The results showed that students' statistical reasoning abilities increased, but the teacher's role still strongly influenced their self-efficacy and confidence in statistics. In addition, Lavigne & Lajoie (2007) conducted a study to determine students' statistical reasoning modes. The results show that students have statistical reasoning in several modes or ways, namely when identifying problems, collecting data, and analyzing data. It was also found that students' statistical reasoning abilities were still simple but could become a basis for further development.

Meanwhile, Idris (2018) conducted a literature review regarding how statistical learning materials should be designed. The finding is that there are three suggested keys in making statistical learning designs: using actual data, familiar contexts, and interactive materials. Rosidah et al. (2018) found that in solving problems related to standard deviation, students with high and low mathematical abilities have mastered the algorithm and can complete procedural calculations well. However, students do not know the concept of standard deviation, so students are unable to interpret the results of data processing. It is the same as the material for measuring data concentration. Students can solve problems procedurally but do not master the concept, so they cannot interpret the results contextually. Another study was conducted by Lee & Kim (2019). This research was conducted to test the textbooks used in Korea and the US America for the statistics class in high school. The results found that the textbook only focused on finding answers to the problems using the formulas learned. Existing texts do not facilitate students to be able to develop statistical reasoning abilities. Rohana & Ningsih (2020) researched at one of the universities in Palembang regarding students' statistical reasoning abilities. The study results showed that students' statistical reasoning abilities were still low and needed more attention to be improved.

Based on several studies conducted abroad and in Indonesia, students' statistical reasoning abilities still need attention. Both are learning outcomes, learning resources, and the learning process. To develop statistical reasoning abilities, students must have a deeper understanding of fundamental statistical concepts (Garfield & Gal, 1999). Statistics is not a branch of mathematics, but statistics are still a mathematical science (Moore in Garfield & Gal, 1999).

Therefore, the researchers believe that an individual's understanding of statistical concepts can be analyzed using the theory used to analyze the knowledge of mathematical concepts. The mental construction of a mathematical concept can be analyzed using the APOS theory. APOS is an acronym for Action (A), Process (P), Object (O), and Schema (S). APOS is a theory that has been highly recognized to describe in detail how students' mental construction works when studying mathematical concepts. Researchers can determine individual understanding of statistical concepts that cause individuals to reason or draw reasonable conclusions based on the statistical information obtained.

The researchers hoped this research could contribute to further research on statistical reasoning abilities, especially in Indonesia. Based on the description above, the researchers are interested in researching the level of students' statistical reasoning abilities based on the APOS theory.

RESEARCH METHOD

This study used a qualitative approach and case study design with a grounded theory perspective. The subjects of this study are students from one of the universities in Bandung. The selected subjects have been confirmed to have studied the material on measures of central tendency and data dispersion. There were 37 students who participated in the statistical reasoning test. As the research had reached saturation, the researchers decided to conclude the interviews with 19 students.

The steps used in grounded theory research are coding techniques. This coding process cannot be separated from the key components (theoretical sensitivity, constant comparison, theoretical sampling, and theoretical saturation). The researchers use theoretical sensitivity in the early stages of coding, which reflects the personal experience of the researcher and the theoretical background in the study of the theory. When coding, the researchers compare one case and another in the same category. The constant comparison of existing cases will quickly produce a theoretical characteristic of the categories found. Constant comparison will direct the researchers to determine the following sample. This process continues until theoretical saturation is reached.

The first coding step is called open coding. At this stage, the researcher coded all the data obtained without discussing it in depth. At this stage, the researchers do not associate the code made with the theory that the researchers get. The code is made substantively based on the data obtained in the field.

The second stage is axial coding. At this stage, the researcher further explored the categories and concepts found in the open coding process. In this case, the researcher will explore the relationship between the categories and concepts found previously.

The last stage is selective coding. This stage integrates and refines the theory in the open and axial coding stages. This process produces one or more core categories that link other categories and concepts.

FINDINGS AND DISCUSSION

The findings were generated based on observations and the results of the informants' statistical reasoning tests, which were also confirmed through interviews. The interviews' results were transcribed and compared with the statistical reasoning test results. Interview results can be an addition or revision of the results of statistical reasoning tests. Next, the researchers coded using Nvivo 12 plus, from open and axial to selective coding.

The researchers found the informants' statistical reasoning level based on the task. The informants were at the idiosyncratic, transitional, quantitative, and analytical statistical reasoning levels. In addition, the researcher found that the informants were at the action, object, process, and schema. The task can be seen in Table 1.

Table 1. Problem and The Indicator

<table>
<tr><th>Indicator</th><th>Problem</th></tr>
<tr><td>Creating a comprehensive data display and representing the data.</td><td>Here is the data of students' mathematics test scores.
<table>
<tr><th>Skor</th><th>Frekuensi</th></tr>
<tr><td>2</td><td>2</td></tr>
<tr><td>3</td><td>4</td></tr>
<tr><td>4</td><td>8</td></tr>
<tr><td>5</td><td>6</td></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>7</td><td>2</td></tr>
<tr><td>8</td><td>1</td></tr>
</table>
What is the shape of the frequency distribution curve? Explain its various characteristics.</td></tr>
</table>

An example of an informant's answer at the idiosyncratic level can be seen in Figure 1.

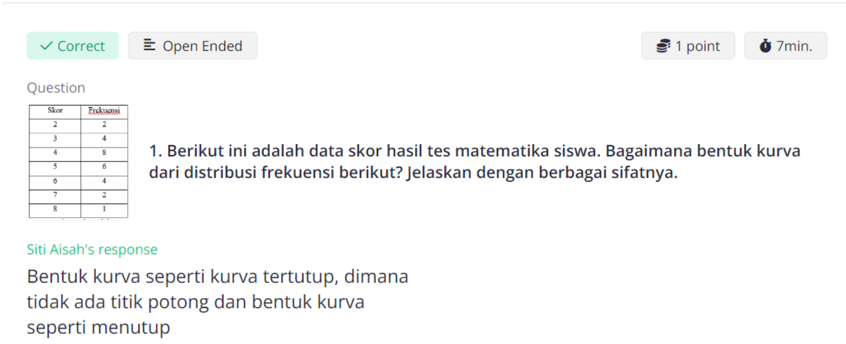

Figure 1. Example of an Informant's Answer at The Idiosyncratic Level

In Figure 1, informants describe the shape of the curve as a closed curve. Researchers need to examine more deeply what informants mean regarding closed curves. Therefore, researchers conducted interviews. The researchers then transcribe the results of the interviews.

Q: Why is the shape closed?

A: This, ma'am, I matched the conditions where the curve is closed, and there are no intersection points. This curve fits the requirements, ma'am.

After seeing the results of the tests and interviews, the researchers understood that in making the data display, the informant's knowledge was affected by previous knowledge about closed curves. This knowledge is less relevant to the data. As a result, the informant cannot represent the data display. Therefore, the researchers categorize the informants at the idiosyncratic level.

An example of an informant's answer at the transitional level category in statistical reasoning is shown in Figure 2.

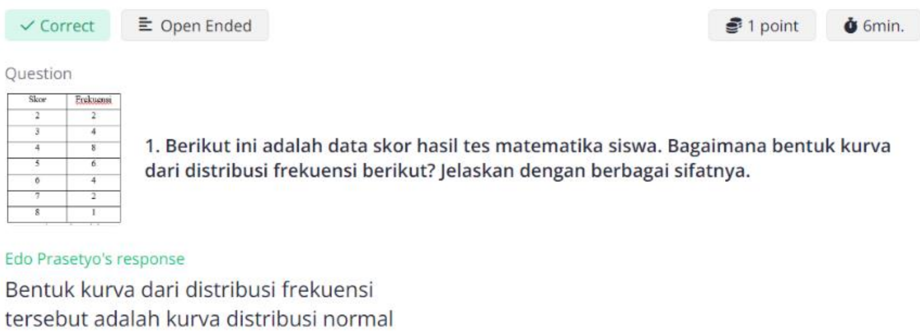

Figure 2. Example of an Informant's Answer at The Transitional Level

In Figure 2, the researchers know that the informant describes the curve as a normal distribution curve. The researcher then confirmed the informant's answer by conducting interviews to determine the steps the informant took to reach these conclusions.

Q: The shape of the curve is a normal distribution curve. How do you get it?

A: I drew it first. Three is four, and four is eight. Then it can be the highest frequency value between four and five.

From the interviews, it can be seen that the informant was able to reason to make a quantitative data display, meaning that the informant was able to make a data display according to the data provided, but the data display described did not represent the data. The frequency distribution of the given data should be positively skewed or right-skewed. Therefore, researchers categorize informants at the transitional level.

Furthermore, at the quantitative level, an example of the results of the informant test is shown in Figure 3.

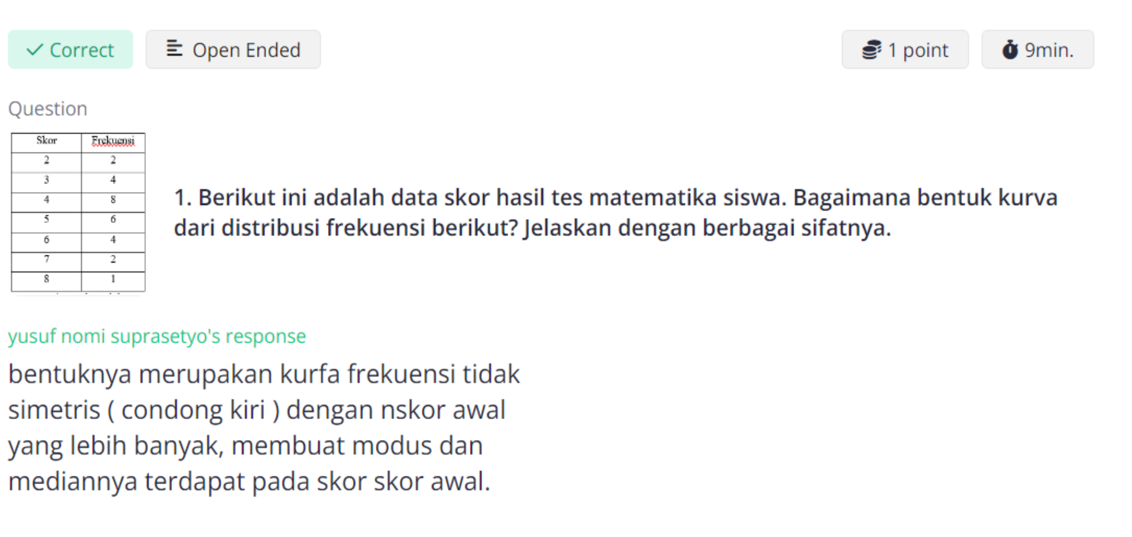

Figure 3. Examples of Answers at the Quantitative Level

From Figure 3, the researchers want to reconfirm the informants' understanding of the skewed curve to the left. The researchers then conducted interviews and transcribed them as follows.

Q: You answered that the curve is not symmetrical and leans to the left. How to get it?

A: Thinking leans to the left because if you use the average or mode formula, the number 4 with a frequency of 8 has more numbers, so there are more to the left.

Researchers categorize informants at the quantitative level from the results of tests and interviews. The informant could display the data, but there was a slight error when describing that the curve is skewed to the left, which means it is negatively skewed. From the informant's statement, which stated that the mode and median were at the initial score, the researcher concluded that what the informant meant was a right-skewed or positive curve.

Finally, the researchers found an informant with an analytical reasoning level. Sample answers at the analytical level are shown in Figure 4.

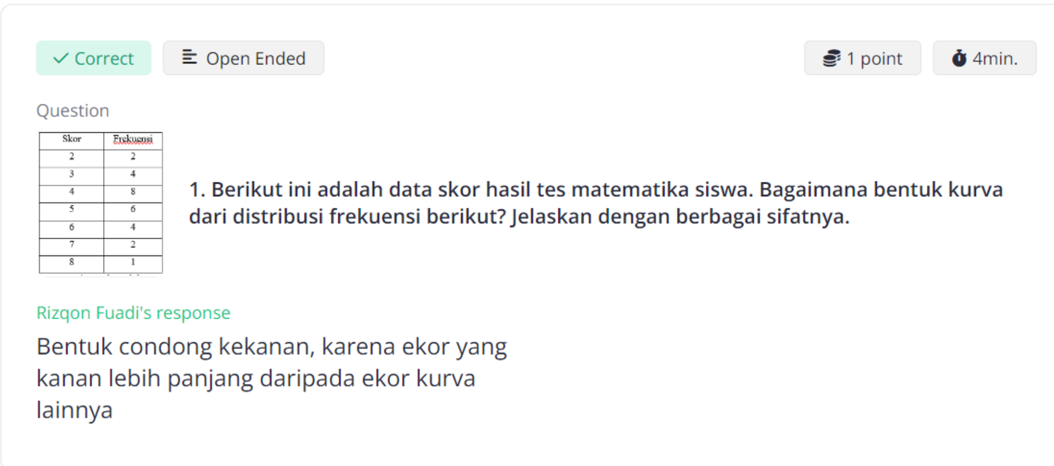

Figure 4. Examples of Answers at the Analytical Level

Regarding the informant's answers, the researchers conducted interviews to get an explanation regarding the informant's understanding of the shape of the curve. The results of the interviews with the researcher are transcribed as follows.

Q: Leaning to the right, how do you get it?

A: For me, ma'am, it's made a curve. The score is from 2 to 8. So the frequency is at most 4. So from 2 to 4, the score goes up, then from 5 to 8, it goes down. I said, leaning to the right because of the tail. The tail is longer at the right. If you go up to the top, it's on the left.

At the analytical level, informants can present data in a complete, representative, and appropriate manner for the given data set and context. Looking at the results of the tests and interviews, the informant can accurately describe how to present the data and represent it according to the context. Therefore researchers categorize informants at the level of analytics.

After categorizing based on the Level of statistical reasoning ability, the researchers categorized the interview results based on the APOS theory. Researchers considered observing more interview results because the informant's understanding of the concept was more visible in the interview results. But researchers also looked at the test results for comparison.

The researchers found that the informants were at the action, object, process, and schema stages. The following is an example of categorizing informant interview results at the action stage.

Q: Why not fill in? Is time running out?

A: Not running out of time, but I don't understand.

Q: Where do you not understand?

A: Yes, it fits the curve part

Q: But have you ever heard of curves?

A: Yes, ma'am, I did, but I forgot.

The interviews show that the informant needs external stimulation to understand the concept of displaying data, in this case, making a curve. Therefore, the informant is categorized in the action stage in understanding the concept of creating and representing data displays.

Furthermore, the following is an example of categorizing the results of interviews at the process stage.

Q: What does the normal frequency look like?

A: The shape of the normal frequency curve is that each shape of the curve has the same distance. So the shape of the curve will be smooth.

Q: Smooth is like what?

A: It's like a mountain going up or down, so each from 1st to 2nd has the same scale

Q: Where did you see it?

A: I drew a graph from the score. With a score of 2, the frequency is 1. For score 3, the frequency is 4. Like this, ma'am (shows a graphic image of the bell leaning to the right)

The results of this interview indicate that the informant no longer needs external stimulation to make a curve. Informants can flexibly describe the steps to make a curve. This occurrence happened due to repetition in the action stage, so the informant entered the process stage. Students' understanding has not been encapsulated into an object. In this case, the shape of the curve is right-leaning, left-leaning, or symmetrical. Unlike the case with the following informants.

Q: Your answer is leaning to the left, which means the slope is positive. Can you explain how you got this answer?

A: There is a table, right, ma'am, the score and frequency. I will first describe the graph. So, if the graph is not symmetrical or leans to the left, what I know is that the shape of the curve is symmetrical, there is a left and right leaning, so if it leans to the left, the slope is positive.

The informant reached the object stage because steps making curve encapsulated into a skewed to the left, skewed to the right, or symmetrical. The informants have not yet reached the schema stage because the actions, processes, and objects are disconnected. We can see from the inaccurate problem-solving. Look at the other case with the following interview results.

Q: Leaning to the right, how do you get it?

A: For me, ma'am, it's made a curve. The score is from 2 to 8. So the frequency is at most 4. So from 2 to 4, the score goes up, then from 5 to 8, it goes down. I said, leaning to the right because of the tail. The tail is longer at the right. If you go up to the top, it's on the left.

Based on the results of this interview, the informants were categorized as having entered the schema stage. This is characterized by correct problem-solving. The informants' action, process, and object stages have been connected to produce the right problem-solving.

The researchers then saw the connection from the results of categorizing informants' answers, both tests and interviews. This step is called axial coding. Researchers used Nvivo 12 plus software to see the relationship between categories. The results of the axial code regarding the relationship between the action category and other simplified categories are shown in Figure 5.

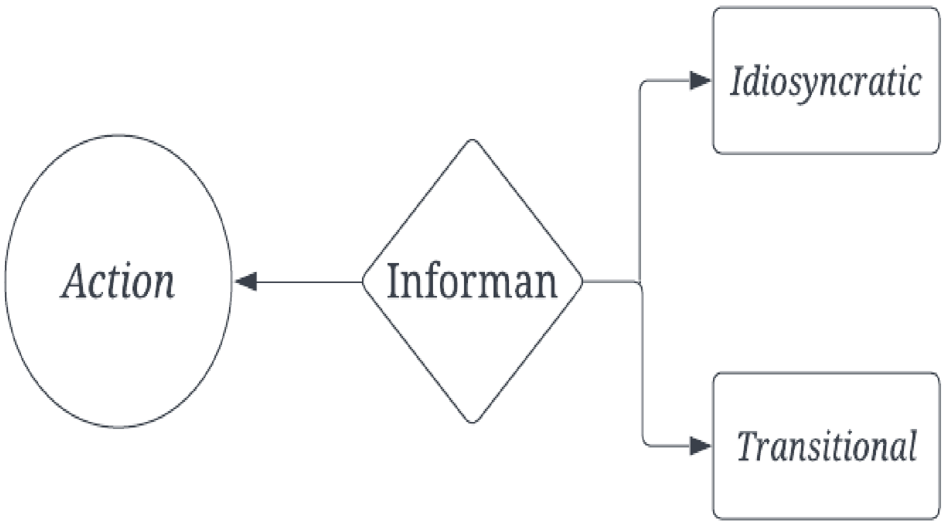

Figure 5. Relationship between Action Category and Other Categories

Based on Figure 5 informants at the action stage have statistical reasoning abilities at the idiosyncratic or transitional level. Informants who are at the idiosyncratic Level and the action stage still need an external stimulus to be able to display data and represent data. Meanwhile, informants at the transitional Level and the action stage can display data despite errors in representing it. Besides that, the informant still needs to be given external stimuli. External stimulus is in the form of a question that revives the informant's memory regarding the appearance of the data and its nature.

Next, the researcher observes the relationship between the process category and another category -namely, the level of statistical reasoning-. The results of the simplified axial code regarding the relationship between the process category and other categories are shown in Figure 6.

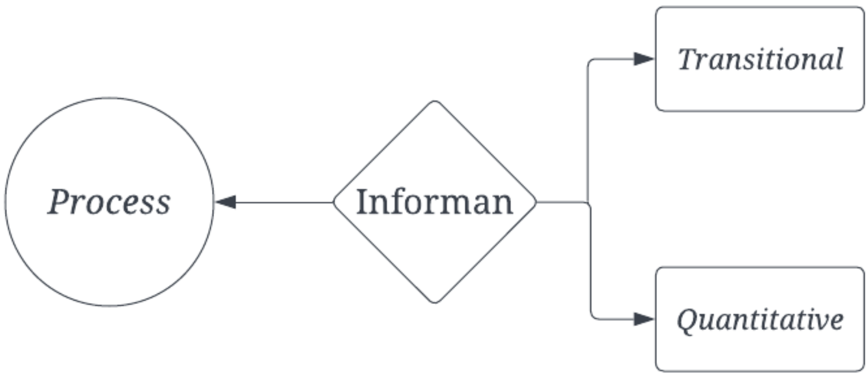

Figure 6. Relationship between Process Category and Other Categories

Based on Figure 6 informants at the process stage also have statistical reasoning abilities at the transitional or quantitative levels. Informants at the transitional level and the process stage no longer need external stimuli to display data, even though the data display is only partially complete but does not represent data or is complete but represents data. At the quantitative level and the process stage, the informant can display data and represent it even if there is a slight error. The step for making the data display already exists within the informant. The informant no longer needs external stimulus, but the informant's understanding has not been encapsulated in "left-leaning, right-leaning, or symmetrical curve shapes."

There are also relationships between object categories and other categories. The results of the simplified axial code regarding the relationship between object categories and different categories are shown in Figure 7.

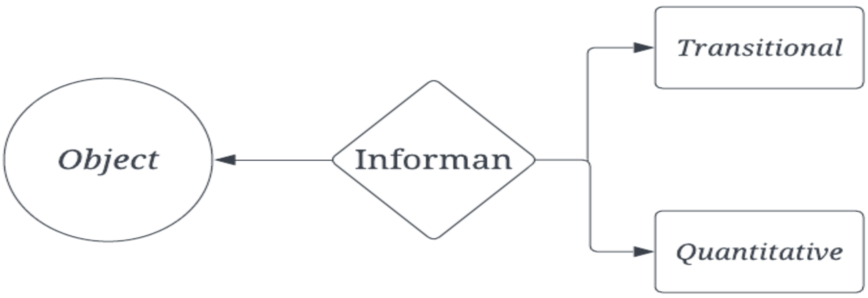

Figure 7. Relationship between Object Categories and Other Categories

Based on Figure 7 informants at the object stage also have statistical reasoning abilities at the transitional or quantitative Level. At the transitional Level, informants can display data but make mistakes when representing it. At the quantitative level, informants can make data displays, represent them, and explain the shape of the curve and its nature. The informants' understanding of the transitional and quantitative levels at the object stage has been encapsulated in "left-skewed, right-skewed, or symmetrical curves."

Finally, We discuss the relationship between schema categories and other categories. The simplified relationship between schema categories and different categories is shown in Figure 8.

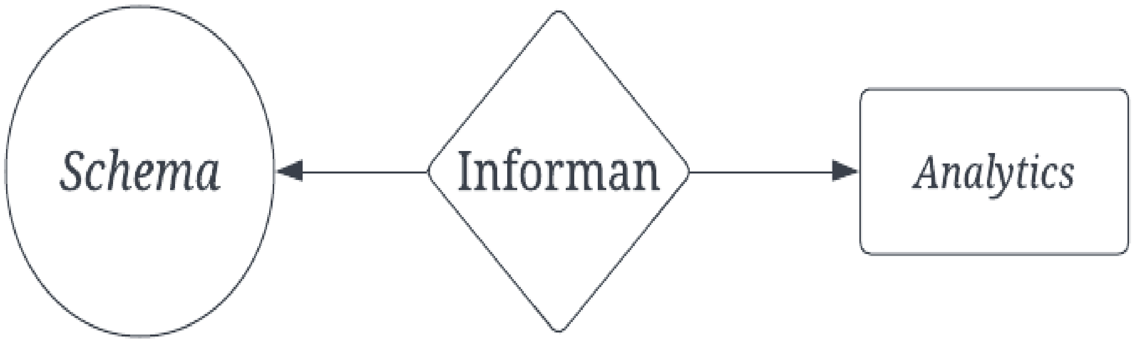

Figure 8. Relationship between Schema Category and Other Categories

Based on Figure 8 informants at the schema stage also have statistical reasoning abilities at the analytics level. Researchers found a relationship that at the level of analytics, informants can make data displays and represent them and can also explain the shape of the curve in question and its nature precisely and validly. The informant's action, project, and object stages at the schema stage are interconnected so that the informant can answer the problems given correctly.

After the categories are linked, the researcher performs the selective coding stage by integrating and perfecting the theory found in the open and axial coding stages. Researchers found four core categories that link other categories and concepts. The four core categories are action, process, object, and schema. Visualization of the theory that has been found can be seen in Figure 9.

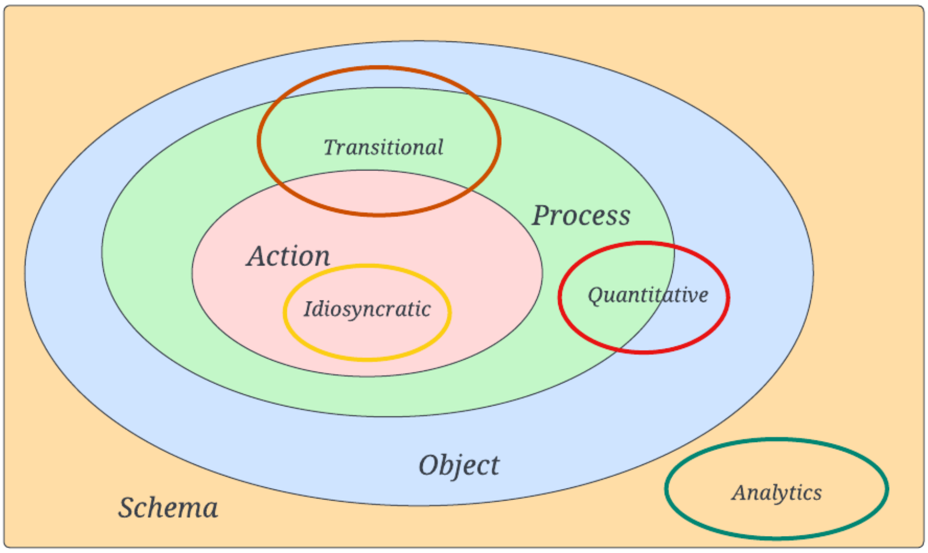

Figure 9. Stages of Selective Coding

Based on Figure 9 in the indicators that make the data display complete and represent the data, the researcher categorizes the informants at the idiosyncratic, transitional, quantitative, and analytical levels. Besides that, informants are classified at the action, process, object, and schema stages.

Informants at the idiosyncratic level generally describe the shape of the curve with steps that are not formal or influenced by the knowledge obtained by the informant beforehand—for example, a closed or positive curve because the calculation uses a specific formula. The informant's answer was acquired because it was influenced by the informant's knowledge of the closed curve and the word "positive" as an operation. Referring to Mooney (2002), individuals are at an idiosyncratic level in the construction process of representing data if they cannot make or display specific data that are incomplete and do not represent data. At the idiosyncratic level, informants are categorized as in the action stage because informants' understanding still requires external stimulus (Arnon et al., 2014; Dubinsky et al., 2005). Knowledge of the curve shape did not internalize. The informant cannot accurately describe the curve shape from the data provided

Informants at the transitional level generally describe the shape of the curve with quantitative reasoning, but in using their reason, they are still inconsistent. In the sense that the informant has started to use proper steps but is not yet appropriate in solving the context of the problem given. For example, a closed or positive curve because the calculation uses a specific formula. The informant's answer was obtained because it was influenced by the informant's knowledge of the closed curve and the word "positive" as an operation. Referring to Mooney (2002), individuals are at a transitional level in the construction process of representing data if they can make partly correct data presentations. At this transitional level, some informants are categorized as in the action stage because the informant's understanding still requires external stimulus, process because the steps for making data display have been internalized within the informant, and objects because the steps for making data display have been internalized and encapsulated into a specific curve (Arnon et al., 2014; Dubinsky et al., 2005).

Informants with a quantitative level can generally describe the shape of the curve with proper steps, but there are a few errors in the naming. For example, the informant tells the shape of the curve as skewed to the right or positive but names it as skewed negatively. Referring to Mooney (2002), individuals are at a quantitative level in the construction process of representing data if they can completely display specific data and represent data but not in context. We categorize the process stage of some informants at the quantitative level because making curve steps internalize within the informants. Some informants are at the object stage because the steps have been encapsulated in a specific curve shape. (Arnon et al., 2014; Dubinsky et al., 2005).

Informants with an analytical level can describe the shape of the curve with formal, precise, and reasonable steps. Informants tell the shape of a positive curve marked by a longer tail on the right. Referring to Mooney (2002), individuals are at an analytical level in the construction process of representing data if they can display specific data that is complete, representative, and following the context of the data provided. At the analytical level, informants are categorized in the schema stage because the action, process, and object stages are interconnected so that informants can answer questions appropriately (Arnon et al., 2014; Dubinsky et al., 2005).

CONCLUSION

Based on APOS theory, informants with the ability to use statistical reasoning at the idiosyncratic level are in the action stage. Individuals still need an external stimulus to understand statistical concepts at the idiosyncratic level. Informants at the transitional level of statistical reasoning ability based on APOS theory are at the process or object stage. Individuals with transitional-level statistical reasoning abilities at the process stage no longer need external stimuli, even though only part of their thinking is valid or acceptable. Meanwhile, individuals with transitional-level statistical reasoning abilities do not need external stimuli at the object stage. Their understanding has been encapsulated in a concept, even though only part of their way of thinking is valid and acceptable, in the sense of using concepts that are still inappropriate for use in a context problem. Informants at the quantitative-level statistical reasoning ability based on APOS theory is at the process or object stage. Individuals who have statistical reasoning abilities at the quantitative Level at the process stage no longer need external stimulus, the steps taken usually use their own valid and acceptable method or a formal method, but there are few errors.

Meanwhile, individuals with statistical reasoning abilities at the quantitative level at the object stage do not need external stimulus, as their understanding has been encapsulated in a concept. The way of thinking used is formal, even though there are slight errors, in that the use of concepts is still inappropriate in a problem context. Informants at the analytical level statistical reasoning ability based on APOS theory is at the schema stage. Individuals who are at the level of analytics can use concepts according to the context of the problem. At this level, the individual action, process, and object stages are interconnected so that individuals can correctly solve problems according to context.

Based on the description above, four conjectures are obtained. Idiosyncratic is in the action stage. Transitional is in the action, process, and object stages. Quantitative is in the process and object stages. Lastly, analytical is at the schema stage.

Future researchers should conduct further research using more samples to reassure about research saturation. In addition, further research is expected with media output, methods, or statistical learning resources based on the conjecture between the Level of statistical reasoning and APOS theory.

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