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Research Article

The Analysis of Students' Critical Thinking Skills in Solving the Generalization Problem of Mathematics Series

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Abstract: Critical thinking is one of the most important thinking skills for students in solving mathematical problems. Hence, students will be able to compete on a global scale when they have the thinking skills; one of them is critical thinking skill. In solving the series of generalization problem, the researcherss divided the problem solving process into three levels of process solutions made by them. This descriptive research employed qualitative approach. The results of students' work were analyzed to determine the level of students' critical thinking skills. Based on the findings, students who had high mathematics skills were classified at critical level (TKBK 3). It indicated that the students were able to find generalization of series. On the other hand, students who had medium mathematics skills were classified at the critical level (TKBK 1). It indicated that they were only able to find the formula S_n to each series, whereas low skills students were at the uncritical level (TKBK 0). It indicated that they were only able to sort out what was known and asked questions.

Key Words: Critical Thinking, Resolving Problem, Generalization of Mathematics Series.

INTRODUCTION

Critical thinking skill is very important competency to be trained to the students because students can examine to the problems that they face, seek and choose a solution precisely. The given level of critical thinking skills of each student is different. It is important for teacher to know and analyze whether the student is a good or not good critics. In fact, student's participation is still low as they tend to be passive in joining a classroom especially at learning mathematics. Consequently, student cannot accustom a critical thinking. The average score of the mathematics test at grade XII MA Darus Sholah students of 2016/2017 was 26,50. It happened due to the students' weakness on critical thinking skills. This fact is same as the opinion of Fritjers et al (in Alfia, 2016) who state that students who graduated from each school in different countries do not have the skills to compete on global scale because they do not have the skills to think critically.

This study analyzed students' critical thinking skills. Ennis (in Alfia, 2016) defines critical thinking ability as a reflective thinking process that focuses on deciding what is believed to be done. Glaser (in Alec, 2009) explains that critical thinking is a willingness to think deeply about problems and things that are within the reach of one's experience. Resolving a problem is a general goal of Mathematics learning which prioritizes the process and strategy done by the students in solving the problem. It must be balanced with the students' critical thinking skills. In this case, the researcherss adopted the critical thinking indicators from the research conducted by Rasiman and Kartinah (2013) that included seven indicators: 1) identifying the facts provided clearly and logically, 2) formulating the issues carefully, 3) applying methods that have been studied accurately, 4) disclosing data/definition/ theorem in solving problems appropriately, 5) deciding and implementing correctly, 6) evaluating relevant arguments in solving a problem thoroughly, 7) distinguishing between conclusions based on logic valid / invalid. Here is a draft of the level of critical thinking skills used by researcherss based on previous research that was the revision of Rasiman and Kartinah.

Table 1. Revision Draft of Critical Thinking Skills Level (TKBK) Students

Critical Thinking Indicator	**TKBK 0**	**TKBK 1**	**TKBK 2**	**TKBK 3**
Identifying the facts provided clearly and logically (IBK 1)	√	√	√	√
Formulating the issues carefully (IBK 2)	√	√	√	√
Applying methods that have been studied accurately (IBK 3)	-	√/-	√/-	√/-
Disclosing	-	√	√	√

data/definition/theorem in solving problems appropriately (IBK 4)				
Deciding and implementing correctly (IBK 5)	-	-	√	√
Evaluating relevant arguments in solving a problem thoroughly (IBK 6)	-	-	√	√
Distinguishing between conclusions based on logic valid/invalid (IBK 7)	-	-	-	√

Description: (Rasiman and Kartinah, 2013)

"-"= does not satisfies the indicator
"√"= satisfies the indicator
"TKBK 0" = Uncritical
"TKBK 1" = Less Critical
"TKBK 2" = Quite Critical
"TKBK 3" = Critical

The researcherss made three levels of solution process in critical thinking skill level (TKBK), namely students at level one (P_1) with ability to look for formula S_n, students at second level (P_2) with ability to prove S_n formula by using mathematical induction, students at level three (P_3) with ability to look find a series generalization, see Table 2. Level of solution process in critical thinking skills level (TKBK)

Table 2. Solution Process Level in TKBK

Problem (P_i)	Indicators of critical thinking
P_1	IBK 1, IBK 2 dan IBK 3
P_2	IBK 4, IBK 5, dan IBK 6
P_3	IBK 1, IBK 2, IBK 6, dan IBK 7

In findings the series generalization, three steps must be completed by the students in which each step of settlement has entered the level of critical thinking skills as in Table 2 above.

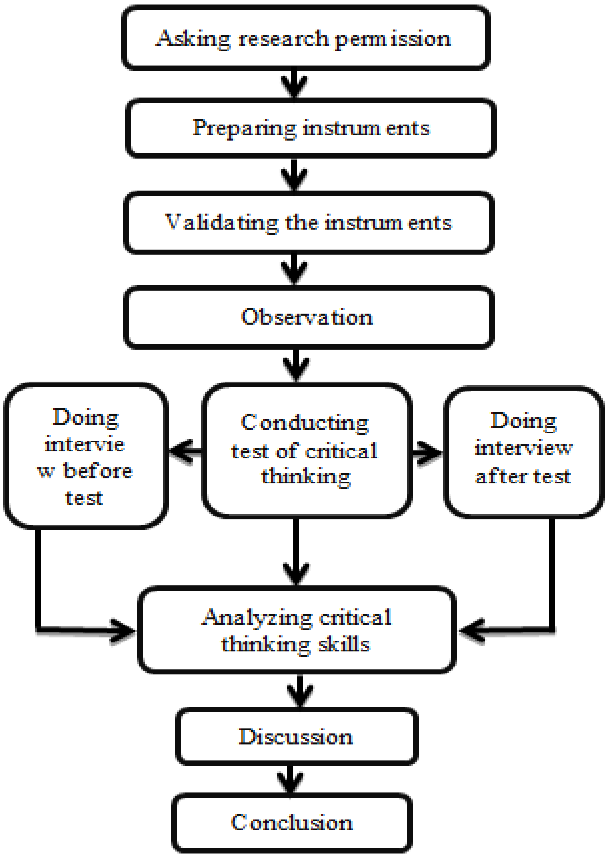
The solution process in finding the S_n formula utilizes factorial polynomials and integral concepts, so it is very different from the way of completion normally used in school mathematics. According to Soehardjo, 2000a (in Mulyani, 2014) formulation an integral form with $\Delta^{-1}x^n = \frac{x^{n+1}}{n+1};\ n \neq -1$ where Δ^{-1} is the integral symbol, the factorial polynomial $x^{(n)} = x(x-1)(x-2)(x-3)\cdots\big(x-(x-1)\big)$ in wich the statement $x^{(n)}$ is read "*x*, *n* factorial" for *n* element ℕ.

RESEARCH METHODS

This descriptive research employed qualitative approach because this research described qualitative and analyzing students' critical thinking skills in solving the series generalization. This research was conducted in Moslem Senior High School of Jember, Indonesia. The research participants consisted of three students of grade 3 who have high, medium and low mathematics skills. Categories of mathematical skills on each subject were determined based on the scores of task, examination, report, National Examination, as well as input from mathematics teachers. The research participants were determined by considering the students' possibility of smooth communication in arguing based on mathematics' teachers input.

The data were analyzed by adopting a model from Miles and Huberman (in Gunawan, 2013) which covered three stages in analyzing qualitative research data that were 1) data reduction, in which researcherss summarized the main points that were considered important in order get more clear information to analyze the data collection; 2) data display, was obtained in the form of students' test and task results as well as the interviews and observations related to the research focus; 3) the conclusion drawing of the researcherss was in the form of data analysis results derived from observation, interview, and test.

The steps in this research were divided into three stages: 1) preparation stage, 2) implementation stage, and 3) final stage of research. 1) Preparation stage: observing the school to be researched, requesting an application letter for a research permit to the Dean of Jember University, submitting an application letter for permission to the principal of Moslem Senior High School of Jember, Indonesia, composing instruments in the form of test questions, observation sheets, and interview guides which each instrument was consulted to the supervisor, then they were validated by the validator, the supervisor, and the examiner. Besides, the researchers prepared the monograph result of the material development of series generalization to assist the researchers in the research process. It was done so that the test questions, observation sheets and interviews used were worthy to be tested. 2) Implementation stage: at this stage, the researchers designated some students to be research participants, interviewed and tested them. Next, the researchers did the observation during the test took place, did interview before and after doing test question given by researchers, and collected data. 3) Final stage: analyzing data, discussing and concluding, requesting research letter to principal of Moslem Senior High School of Jember, Indonesia. In brief, the steps undertaken in this research can be illustrated in the following diagram:



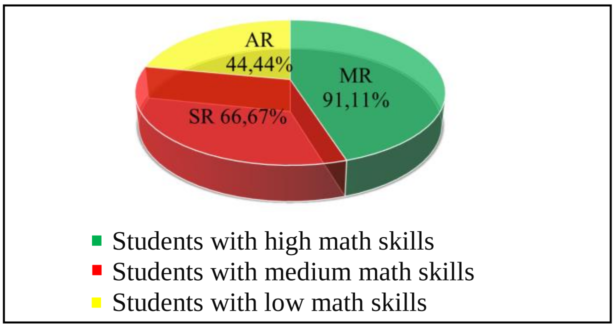
Picture 1. Schematic of Research Implementation

The data measured in this research were test result data, interview result, and observation data of students' critical thinking skills in solving the series generalization problem. The results were devoted to know the students' critical thinking skills based on the seven indicators of critical thinking skills. In addition, the researchers determined whether the students operated critical thinkers or not based on the revision draft of critical thinking skills level of Rasiman and Kartinah in Table 1.

RESULTS AND DISCUSSION

The initial activity of this research was research planning by preparing research instruments such as observation, interview, and test. The instruments were validated by experts. After the validation, it was followed by observing the students' activity during the learning process. The observation stages were done twice, 1) before the test and the interview, 2) during the implementation of the test and the interview. Both stages were presented in the form of the circle diagram as follow.

Observation results of students critical thinking skills



Picture 2. Diagram of Observation Results

Based on the observation results, students with high math skill got percentage of 91,11% that got score 41 from total 45; students with medium math skill got percentage of 66,67% that got score 30 from total 45; and students with low math skill got percentage of 44,44% that got score 20 from total score 45. Besides the results of observation, researchers also presented results of interview and students test.

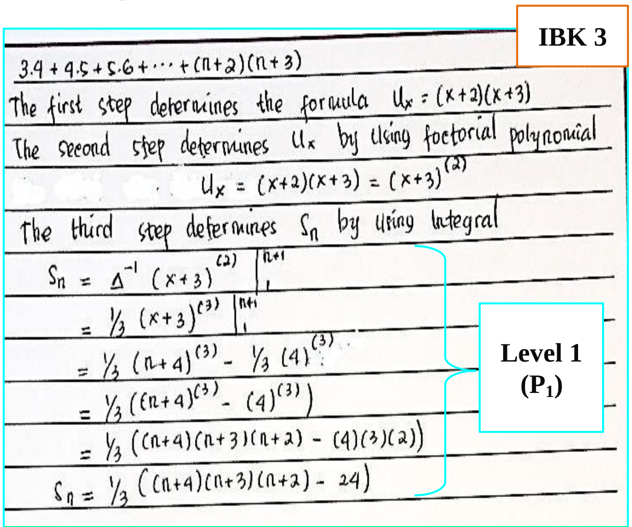
A. *Student with high math skills (MR)*

P : "After you read this question, what can you understand from that problem?"

MR : "(While looking at the problem again), question number 1 is asked to look for S_n formula and prove it that S_n formula is correct in each of these series."**(IBK 1)**

P : "Is there any information you get from the question?
If yes, please try to explain!"

MR : "Yes Mam, there are known three series (while marking the series that exist on the problem) and to be asked S_n formula and prove it that S_n is true. "**(IBK 2)**



Section 1 in determining S_n formula of the student had been able to complete the completion phase to find the S_n formula correctly; so that, the critical thinking indicator (IBK) at level 1 (P_1) was fulfilled.

Picture 3. Student (MR) looking for S_n formula (P_1)

Researchers interview results with MR in proves S_n formula.

P : "How do you prove that S_n is true?"

MR : "Using math induction. There are two stages, first testing n=1 hold the second n=k is considered correct, so n=k+1 is also true. "**(IBK 4)**

P : "Are the steps proving S_n formula correct?"

MR : "Yes, they are correct, because the two stages in the mathematical induction step are proven true (while showing the result of the answer), so S_n formula is right."**(IBK 6)**

Level 2 (P_2)

Proves S_n formula by using mathematical induction

- for $n=1$, $(n+2)(n+3) = \frac{1}{3}((n+4)(n+3)(n+2)-24)$

$$(1+2)(1+3) = \tfrac{1}{3}((1+4)(1+3)(1+2)-24)$$
$$(3)(4) = \tfrac{1}{3}((5)(4)(3)-24)$$
$$12 = \tfrac{1}{3}(60-24)$$
$$12 = 12 \quad \text{True}$$

- Assume $n=k$, $S_k = 3.4+4.5+5.6+\cdots+(k+2)(k+3) = \frac{1}{3}((k+4)(k+3)(k+2)-24)$

assume correct for $n = k+1$

$$S_{k+1} = \underbrace{3.4+4.5+5.6+\cdots+(k+2)(k+3)}_{\frac{1}{3}((k+4)(k+3)(k+2)-24)} + (k+3)(k+4) = \tfrac{1}{3}((k+5)(k+4)(k+3)-24)$$
$$\tfrac{1}{3}((k+4)(k+3)(k+2)-24) + (k+3)(k+4) = \tfrac{1}{3}((k+5)(k+4)(k+3)-24)$$
$$\tfrac{1}{3}((k^2+3k+4k+12)(k+2)-24)+(k^2+4k+3k+12) =$$
$$\tfrac{1}{3}((k^2+7k+12)(k+2)-24)+(k^2+7k+12) =$$
$$\tfrac{1}{3}(k^3+2k^2+7k^2+14k+12k+\cancel{24}-\cancel{24})+(k^2+7k+12) =$$
$$\tfrac{1}{3}(k^3+9k^2+26k) + (k^2+7k+12) =$$
$$\tfrac{1}{3}(k^3+9k^2+26k+3k^2+21k+36) =$$
$$\tfrac{1}{3}(k.(k^2+7k+12)+5(k^2+7k+12)-24) =$$
$$\tfrac{1}{3}((k+5)(k^2+7k+12)-24) = \tfrac{1}{3}((k+5)(k+4)(k+3)-24)$$

So S_{k+1} is true.

Part 2, the student had been able to consider the correct formula in validating S_n formula by using mathematical induction (IBK 4), the student was able to complete every correct and correct induction step (IBK 5), beside that the student was also able to give explanation and match the results obtained with the questions asked on the problem (IBK 6). Hence, the critical thinking indicator (IBK) that existed at level 2(P_2) is met.

Picture 4. Student (MR) proves S_n formula with mathematical induction (P_2)

Researchers interview results with MR in finding the series generalization

P : "Can you find the series generalization?"

MR : "Yes Mam, we see the pattern on S_n formula."**(IBK 6)**

P : How do you prove that the series generalization you found is correct?"

MR : "Yes, we simply take the example of a series that has been proved the precision of the formula (S_n). After we find the formula S_n with the generalization, we match whether the formula is the same as S_n formula with the previous step."**(IBK 6)**

P : "So?"

MR : "The equation means the generalization formula of this series is true because each previous series has been proved to be true using mathematic induction."**(IBK 7)**

Completion :

Known : i) $3+4+5+\cdots+(n+2)$
ii) $3.4+4.5+5.6+\cdots+(n+2)(n+3)$
iii) $3.4.5+4.5.6+5.6.7+\cdots+(n+2)(n+3)(n+4)$

Asked : Generalization of the series

Answer : Because the series form is equal to the number (1), then there is no need to look for S_n formula

Series Pattern	S_n Formula
$3+4+5+\cdots+(n+2)$	$\frac{1}{2}((n+3)(n+2)-6)$
$3.4+4.5+5.6+\cdots+(n+2)(n+3)$	$\frac{1}{3}((n+4)(n+3)(n+2)-24)$
$3.4.5+4.5.6+\cdots+(n+2)(n+3)(n+4)$	$\frac{1}{4}((n+5)(n+4)(n+3)(n+2)-120)$
	$\vdots$

Level 3 (P_3)

So the generalization of this series is

$$\frac{1}{p+1}\left((n+(p+2))^{(p+1)} - (p+2)^{(p+1)}\right)$$

with the provision of
- The first number on tribe 1 (a) = 3
- Difference (b) = 1
- p = Many numbers of each tribe
- $\left.\begin{matrix}(n+(p+2))^{(p+1)} \\ (p+2)^{(p+1)}\end{matrix}\right\}$ factorial polynomial

Make a series example by applying the generalization of the series above!

- for example of series $3.4+4.5+5.6+\cdots+(n+2)(n+3) = \frac{1}{3}((n+4)(n+3)(n+2)-24)$

$p=2$; $a=3$; $b=1$

$$S_n = \tfrac{1}{p+1}\left((n+(p+2))^{(p+1)} - (p+2)^{(p+1)}\right)$$
$$= \tfrac{1}{2+1}\left((n+(2+2))^{(2+1)} - (2+2)^{(2+1)}\right)$$
$$= \tfrac{1}{3}\left((n+4)^{(3)} - (4)^{(3)}\right)$$
$$= \tfrac{1}{3}((n+4)(n+3)(n+2) - (4)(3)(2))$$
$$= \tfrac{1}{3}((n+4)(n+3)(n+2) - 24) \quad \square$$

- Series form $3.4.5+4.5.6+\cdots+(n+2)(n+3)(n+4) = \frac{1}{4}((n+5)(n+4)(n+3)(n+2)-120)$

$$S_n = \tfrac{1}{3+1}\left((n+(3+2))^{(3+1)} - (3+2)^{(3+1)}\right)$$
$$= \tfrac{1}{4}\left((n+5)^{(4)} - (5)^{(4)}\right)$$
$$= \tfrac{1}{4}((n+5)(n+4)(n+3)(n+2) - (5)(4)(3)(2))$$
$$= \tfrac{1}{4}((n+5)(n+4)(n+3)(n+2) - 120) \quad \square$$

Section 3 (P_3), students were able to understand the information on the problem. The students were able to sort out what was known and what questions were asked (IBK 1 and 2). Students were able to provide arguments in completing the generalization phase of the series. The students were able to match the results obtained with those asked (IBK 6). Students were able to make correct conclusions based on the results obtained (IBK 7). So that, the Critical Thinking Indicators (IBK) that existed at level 3 (P_3) were met.

Picture 5. Student (MR) found the series generalization (P3)

B. *Student with medium math skill (AR)*

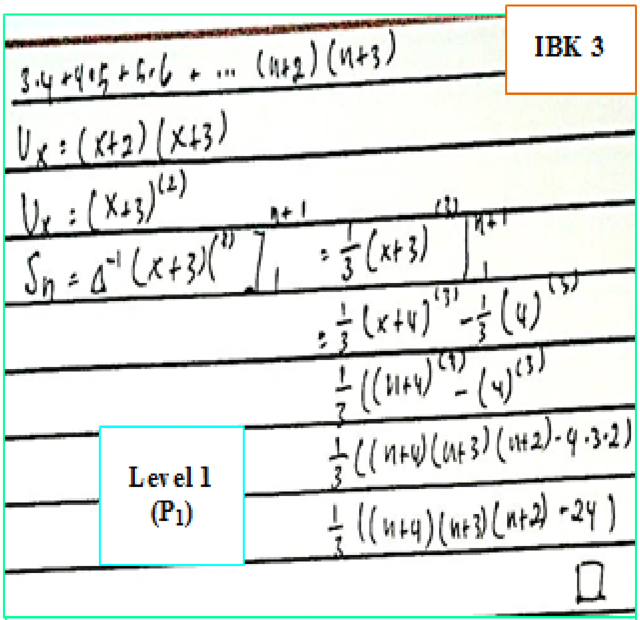
Researchers interview results with AR in finding the S_n formula.

P : "After you read this question, what can you understand from that problem?"

AR : "(While looking at the problem again) there is form of series that we want to find the S_n formula."**(IBK 1)**

P : "Is there any information you get from the question?
If yes, please try to explain!"

AR : "(While looking at the problem again) yes Mam, it is known that there are three series, which is asked S_n formula and proves S_n formula is true."**(IBK 2)**



Section 1 in determining S_n formula of the student had been able to complete the completion phase to find the S_n formula correctly, so the Critical Thinking Indicator (IBK) at level 1 (P_1) was satisfied.

Picture 6. Student (AR) looks for S_n formula (P_1)

Researchers' interview results with AR proving S_n formula.

P : "How do you prove that S_n is true?"

AR : "Using mathematical induction (while looking at the monograph), testing n = 1 continuously n = k is considered true, so n = k + 1 is also true." **(IBK 4)**

P : "Are the steps in S_n formula correct?"

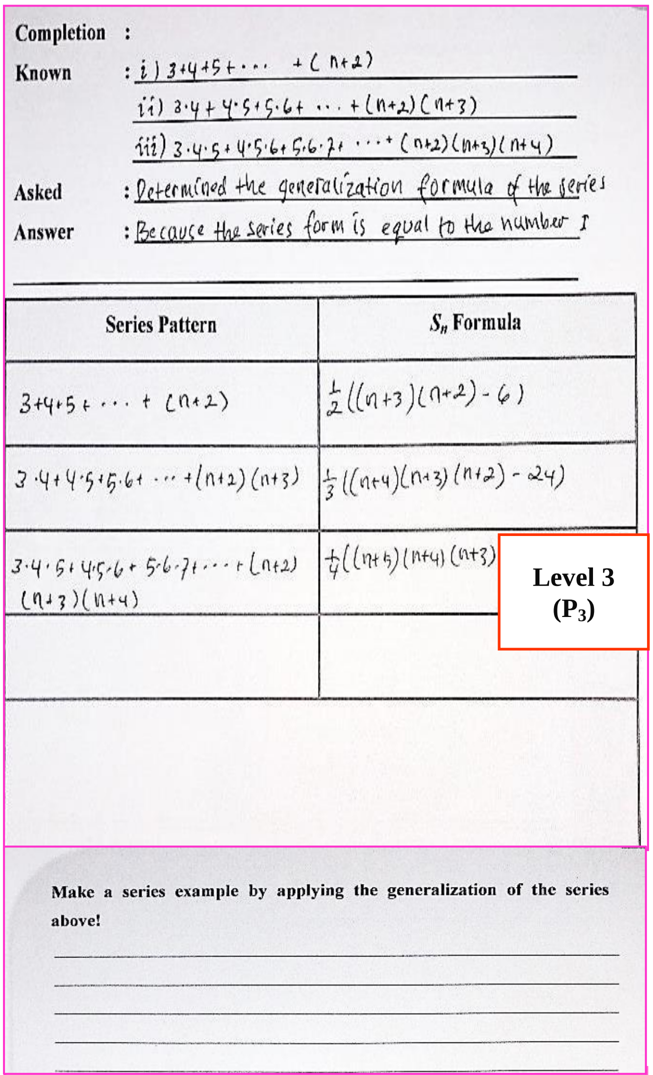
AR : Emmm Insya Allah it may be true." **(IBK 6)**

P : "Why is it still possible?"

AR : "Because I cannot prove that S_n formula is correct due to on step n = k + 1 number 1b) and c), so it's a bit doubt the formula is right or not."

P : "Have you checked the counting process on mathematical induction?"

AR : "It has been already done (while looking at his work and check the results of the answer), but I still do not find what is wrong."



Section 3 (P_3), students were able to understand the information on the problem, and the students were able to sort out what was known and what questions were asked (IBK 1 and 2). Students were not able to provide arguments in completing the generalization stage of the series. Moreover, students were unable to match the results obtained with those asked (IBK 6). Students were not able to make correct conclusions based on the results obtained (IBK 7). Hence, the indicator of Critical Thinking Indicator (IBK) existed at level 3 (P_3) only was partially fulfilled of IBK 1 and 2.

Picture 7. Student (AR) proves S_n formula with mathematical induction (P_2)

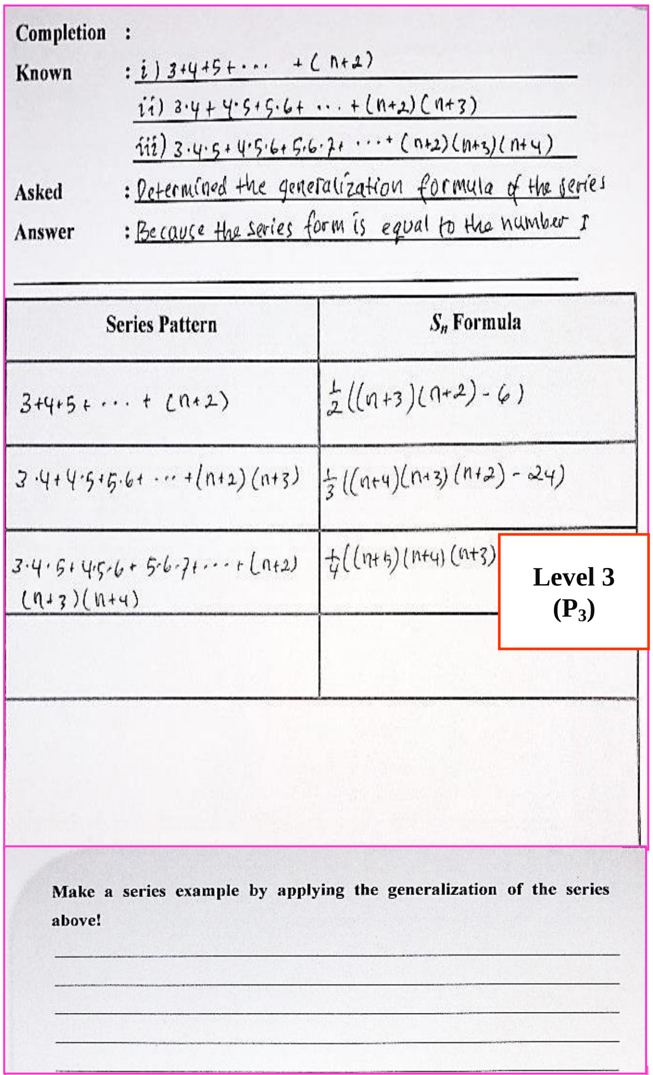
Researchers interview results with AR in finding the series generalization.

P : "Can you find the generalization of the series?"

AR : "I'm confused Mam." **(IBK 6)**

P : "What can you conclude from problems 1 and 2? "

AR : While looking at the results of his work) there are three forms of the series." **(IBK 6)**



Completion :

Known : i) $3+4+5+\cdots+(n+2)$

ii) $3\cdot4+4\cdot5+5\cdot6+\cdots+(n+2)(n+3)$

iii) $3\cdot4\cdot5+4\cdot5\cdot6+5\cdot6\cdot7+\cdots+(n+2)(n+3)(n+4)$

Asked : Determined the generalization formula of the series

Answer : Because the series form is equal to the number I

Series Pattern	S_n Formula
$3+4+5+\cdots+(n+2)$	$\frac{1}{2}((n+3)(n+2)-6)$
$3\cdot4+4\cdot5+5\cdot6+\cdots+(n+2)(n+3)$	$\frac{1}{3}((n+4)(n+3)(n+2)-24)$
$3\cdot4\cdot5+4\cdot5\cdot6+5\cdot6\cdot7+\cdots+(n+2)(n+3)(n+4)$	$\frac{1}{4}((n+5)(n+4)(n+3)$

Level 3 (P_3)

Make a series example by applying the generalization of the series above!

Section 3 (P_3), students were able to understand the information on the problem, and the students were able to sort out what was known and what questions were asked (IBK 1 and 2). Students were not able to provide arguments in completing the generalization stage of the series. Moreover, students were unable to match the results obtained with those asked (IBK 6). Students were not able to make correct conclusions based on the results obtained (IBK 7). Hence, the indicator of Critical Thinking Indicator (IBK) existed at level 3 (P_3) only was partially fulfilled of IBK 1 and 2.

Picture 8. Student(AR) finds generalization of series(P_3)

C. *Student with low math skills (SR)*

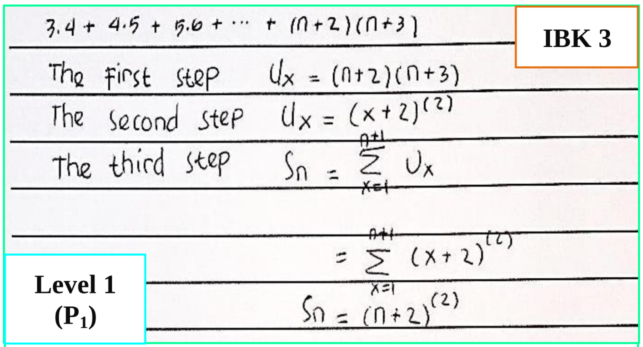
Researchers interview results with SR in finding the S_n formula.

P : "After you read this question, what can you understand from that problem?"

SR : There is a series of forms" **(IBK 1)**

P : "Is there any information you get from the question? If yes try to explain!

SR : Yes, Mam, (while looking at the problem), I found the formula of sum and the first rate (S_n) in each of these series and prove the formula (S_n) is true."**(IBK 2)**



$3\cdot4+4\cdot5+5\cdot6+\cdots+(n+2)(n+3)$

IBK 3

The first step $U_x=(n+2)(n+3)$

The second step $U_x=(x+2)^{(2)}$

The third step $S_n=\sum_{x=1}^{n+1}U_x$

$=\sum_{x=1}^{n+1}(x+2)^{(2)}$

$S_n=(n+2)^{(2)}$

Level 1 (P_1)

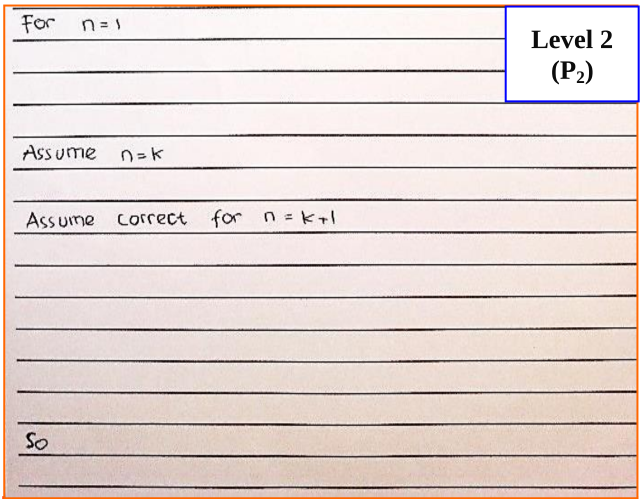
Section 1 in determining S_n formula, student was not able to complete the completion phase of finding S_n formula correctly; so that, the Critical Thinking Indicator (IBK) at level 1 (P_1) was partially fulfilled (IBK 1 and 2). The student was only able to sort out what was known and asked questions.

Picture 9. Student (SR) looking for S_n formula (P_1)

Researchers' interview results with SR proving S_n formula.

P : "How do you prove that S_n is true?"

SR : "Using mathematical induction, but I am confused how to do it." **(IBK 4)**



For $n=1$

Level 2 (P_2)

Assume $n=k$

Assume correct for $n=k+1$

So

Section 2 in validating S_n formula, the student was not able to finish it well. It could be seen from the blank student's worksheet. Hence, the critical thinking indicator that existed at level 2 was not met.

Picture 10. Student (SR) proves S_n formula with mathematical induction (P_2)

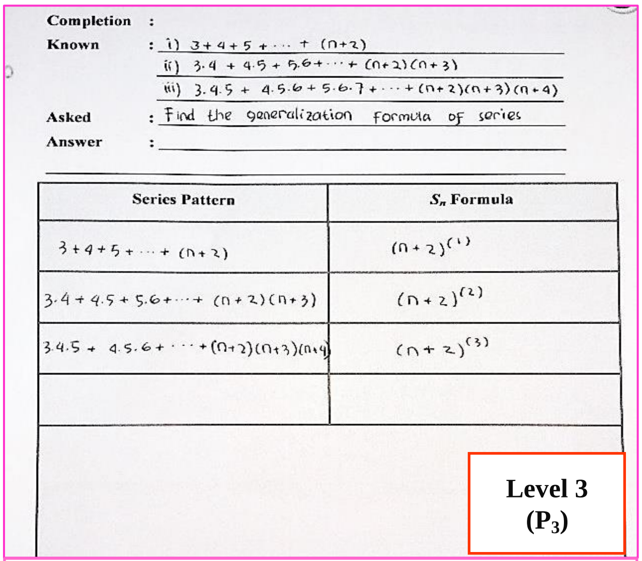
Researchers' interview results with SR in finding the series generalization.

P : "Can you find the series generalization?"

SR : "I dont know, it is difficult." **(IBK 6)**

P : What can you conclude from problems 1 and 2?"

SR : "Not sure Mam, I'm confused, because I have trouble in finding the formula." **(IBK 6)**



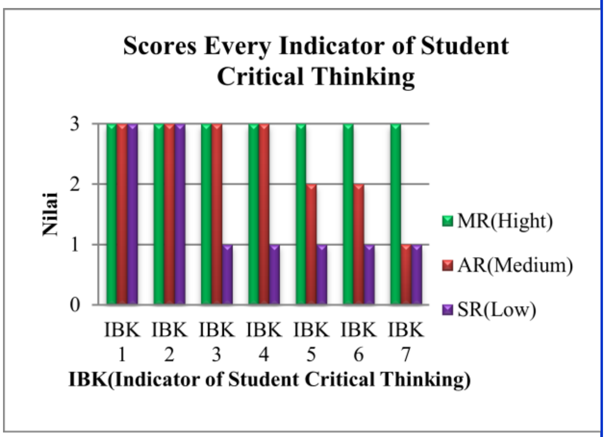
Completion :
Known : i) 3 + 4 + 5 + ··· + (n+2)
ii) 3·4 + 4·5 + 5·6 + ··· + (n+2)(n+3)
iii) 3·4·5 + 4·5·6 + 5·6·7 + ··· + (n+2)(n+3)(n+4)
Asked : Find the generalization formula of series
Answer :

Series Pattern	S_n Formula
3 + 4 + 5 + ··· + (n+2)	$(n+2)^{(1)}$
3·4 + 4·5 + 5·6 + ··· + (n+2)(n+3)	$(n+2)^{(2)}$
3·4·5 + 4·5·6 + ··· + (n+2)(n+3)(n+4)	$(n+2)^{(3)}$

Section 3 (P_3), students were able to understand the information on the problem. The students were able to sort out what was known and asked questions (IBK 1, and 2). Students were not able to provide argument. Students were not able to provide arguments in completing the generalization stage of the series. Students were unable to match the results obtained with those asked (IBK 6). Students were not able to make correct conclusions based on the results obtained (IBK 7). Hence, the Critical Thinking Indicator (IBK) that existed at level 3 (P_3) was partially met that were only IBK 1 and 2.

Picture 11. Student (SR) finds the series generalization (P_3)

Based on the exposure analysis of critical thinking skills in each student above, data can be presented into the bar chart, which explains the score of each indicator of students' critical thinking.

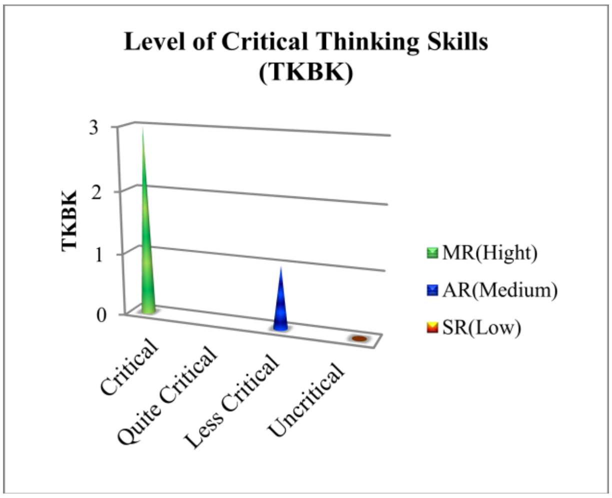


Keterangan:
Value 3 = IBK of each problem solving is met all
Value 2 = IBK of each problem solution is partially fulfilled
Value 1 = IBK of each problem solving is not met

Picture 12. Score diagram of each indicator of student's critical thinking

Students having high math skill (MR) met all critical thinking indicators. Students having medium math skill (AR) only met 4 indicators of critical thinking skills that were IBK 1 to 4 because students were incapable of completing the proof of the series formula. Moreover, it was true that in the other multilevel series. The students were also unable to find the asked questions of series generalization. Students having low math skill (SR) were only able to meet 2 critical thinking indicators that were (IBK) 1 and 2 because students were only able to understand the problem and sort out what was known and asked on the question. The student incorrectly applied the formula, both in finding the S_n formula and any proof S_n formula with mathematical induction.

Based on the diagram above, it can be seen also the level of critical thinking skills of the three students. The following is the level of students' critical thinking skills in solving the series generalization.



Picture 13. Graphic level of students' critical thinking skills

Based on the graph above, it showed that students having high math skill were at a critical level (TKBK 3). It means that students were able to meet the three levels of questions made by researchers, so they were able to find the series generalization. Students having medium math skill were at a less critical level (TKBK 1). The students were only able to meet some critical thinking indicators on each level of questions made by the researchers, while students having low math skill were at uncritical level (TKBK 0) because only two critical thinking indicators were fulfilled.

CONCLUDING REMARK

Teachers bring their research into learning, so students may know the new materials that have never been presented before, and they can be used as materials for students' enrichment. This is because this series of generalization material has not been studied at high school level especially MA/SMA/SMK which is only limited in finding formula the series and how to find the S_n formula is different from the usual completion steps taught to the students. In this case, the students were brought to a situation that made them process the critical thinking because after students find the formula of each series then students were required to find the series generalization. It made the students' answers vary among students.

Based on the analysis of students' critical thinking skills, only one student at critical level (TKBK 3) was able to find the S_n formula correctly, able to prove the correct S_n formula and able to find the series generalization correctly. Therefore, the researchers provide suggestions for further research, including as follows:

- Novelty of study in a research must be present.
- Research participants must reach saturation point. For example, using snowball method (snowball sampling methods) in sampling, so the research can be carried out to tap into the level of students' critical thinking skills.

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