e-ISSN: 2549-5070
p-ISSN: 2549-8231

Journal of Medives : Journal of Mathematics Education IKIP Veteran Semarang
Volume 6, No. 2, 2022, pp. 133-146

https://doi.org/10.31331/medivesveteran.v6i2.2084

Assessing Proceptual Understanding In the Context of Connected Classroom

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Received: *May 2022.* ***Accepted***: *June 2022.* ***Published***: *July 2022.*

ABSTRACT

Some mathematics teachers in Indonesia still find it challenging to conduct a formative assessment in a class with many students. A problem emerges in how to facilitate an environment that uses the type of engaging discussion needed for formative assessment to be successful. Meanwhile, in mathematics learning, proceptual (process and conceptual) understanding is considered prominent for success in learning mathematics. This understanding could be enhanced by using an appropriate strategy of discussion, which could be managed along with conducting a formative assessment. Overcoming this challenge, promoting a connected classroom might be beneficial to facilitating formative evaluation in a large class. Therefore, this paper aims to develop a method for formatively assessing students' mathematics understanding that mathematics teachers could use with a focus on proceptual understanding. Reviewing some literature on the topics of mathematics understanding, formative assessment, and connected classroom has established a framework to help teachers develop guidance for conducting formative assessment in proceptual understanding using a connected classroom. The framework based might be used to help mathematics teachers prepare formative assessments in a class with many students. An example of how to develop a guide to assess students' proceptual understanding of algebra is also provided in this paper.

Keywords: *proceptual understanding, formative assessment, connected classroom*

How to Cite: Ernawati, E. (2022). Assessing Proceptual Understanding In the Context of Connected Classroom. *Journal of Medives: Journal of Mathematics Education IKIP Veteran Semarang*, *6*(2), 133-146.

INTRODUCTION

When I was a mathematics tutor, I used to find that some of my students would struggle at solving complex equations. My students seemed pessimistic whenever they found a problem that required them to solve it using an algebraic equation. Basically, I was a tutor in a cramming school in which students from different schools came together to have additional learning time out of their formal school. The students came to me because they did not quite understand their teachers' explanations. The phenomenon of students coming to a cramming school has been gradually increasing in Indonesia. This phenomenon reflects that teaching and learning processes at some schools seem less effective. I believe that there may be some solutions to this problem and one of them is to improving students' learning through formative assessment.

However, formative assessment is often overlooked by some teachers in Indonesia. In my opinion, this phenomenon could happen because prospective teachers are more likely to be taught about mastering summative assessment as opposed to considering formative assessment techniques. Whereas, according to Irving (2006), summative assessment cannot support teachers' decision making in daily lessons. Moreover, Irving argued that teachers have struggled to monitor their students' progress in terms of their mathematical understanding if they only use summative assessments. In my experience, pre-service teachers also find a problem to facilitate an environment that makes use of the type of engaging discussion needed for formative assessment to be successful. I suspect that, promoting a connected classroom may be beneficial to overcome the challenge.

Based on my experiences above, in this assignment, I want to develop a method for formatively assessing students' mathematics understanding as a part of a curriculum that could be used by mathematics teachers with a focus on proceptual understanding. Firstly, I want to gain insights by reviewing literature before I construct a framework to develop guidance for teachers to conduct a formative assessment using a connected classroom. To begin with, a literature review about the curriculum will be presented first.

Curriculum

The term curriculum is used differently among some educational researchers. Some researchers frame the curriculum as a process. In other words, the curriculum is what actually happens in the classroom as a result of the interaction between teachers, students, and knowledge (Smith, 2000). Other researchers suggest that curriculum is knowledge to be imparted (Barnett, 1991; Ferry et al, 1998; Cross, 2003).

However, for the purpose of this article, the curriculum is defined as a product. Grundy (as cited in Smith, 2000) claimed that curriculum is planned activities designed for teachers and students to help students accomplishing as far as possible certain educational purposes. Put the claim another way, the curriculum is the proposal of activities to be done in order to achieve certain educational aims. However, Wiliam (2001) claimed that achievement is an indication of a gap between the actual level of performance and the desired one and formative assessment is an action to fill the gap so that the objective planned in the curriculum is attained. Therefore, I will argue that formative assessment is an important aspect in the process of implementing a curriculum. Since this article will discuss assessing

mathematics understanding, before continuing our discussion into formative assessment, let us now consider proceptual understanding which will be explained within a section of mathematics understanding as follows.

Mathematics Understanding

Gray & Tall (1993) define mathematics understanding as procedural thinking and proceptual thinking. They assert that a mathematics symbol can be interpreted in two ways. First, a symbol can be seen as a combined mental object consisting of a process. Then, a symbol can also be interpreted as a concept produced by a process. Thus, procedural thinking refers to the capability to know a symbol only as a process. Meanwhile, proceptual thinking is the capability to see the ambiguity of a mathematics symbol whether as a process or a concept. Hence, proceptual thinkers can use a symbol as a process when appropriate as well as using a symbol as a concept when appropriate. I suspect that Gray & Tall's proceptual understanding is related to relational understanding which is the capability of knowing what to do and why (Skemp, 1976). Working with mathematics means that we might work with mathematical symbols or notions. This work requires us to use a relational understanding to justify our assumption when we see a mathematical symbol either as a procedure or a concept. Even though some said that this capability ultimately becomes automatic or unconscious, to justify that a child has proceptual understanding is to convince that he/she knows what to do and why in the first place.

Gray & Tall (1993) also argue that being able to flexibly use the ambiguity of a symbol will give great mathematical power. This view is supported by Sfard (1991) who said that the capability of differentiating procedural understanding from conceptual understanding is an essential component of mathematical ability. However, Sfard has distinct terms to present mathematical understanding. While Gray & Tall used procedural and conceptual understanding term, Sfard referred to the use of structural and operational notions. Sfard (1991) asserted that there are two possibilities for treating a mathematical notion whether it refers to an operational notion or a structural notion. Interpreting a mathematical entity as a procedural notion refers to a process or algorithm which comes to a sequence of actions. Meanwhile seeing a mathematical notion in a structural view means that interpreting the notions as objects which can be manipulated. Similar to Gray & Tall, Sfard also admits that there is a duality within a mathematical notion that can be interpreted operationally or structurally. Put an algebraic expression "$4a+5b$" as an example. The expression can be seen as a computation process of adding four times a to five times b as well as a concept of the algebraic expression (Gray & Tall, 1993; Sfard, 1991; Drijvers, 2003). Unfortunately, for Indonesian students, seeing the difference of computation processes and concepts within an algebraic expression is still problematic (Jupri et al, 2014).

As mentioned earlier, having a proceptual understanding of mathematics is considered to be crucial in order to be successful in mathematics (Gray & Tall, 1993; Sfard, 1991). Those who cannot aware of this subtle difference will fail, fail badly, and fail often which then leads to the perception that mathematics is complicated and difficult. Therefore, improving children's learning is important, in this case, Gray & Tall (1993) believe that

"only through discussion and listening to a

child talking through the processes being used can one hope to diagnose the possible development of inappropriate strategies. (p. 7)"

Some teachers may prefer to conduct written tests to assess their students' understanding due to the effectiveness of the time consumed. However, some researchers argue that assessing proceptual understanding through written tests are not enough and should be followed up by extension questions (Hunter & Monaghan, 1996). Therefore, I would suggest that providing an environment for discussion may be a potential solution for assessing students' proceptual understanding. Before we continue the discussion, it is important to define what the purpose of assessment in this essay is. Since the assessment aims to improve the children's learning hence I would refer it as a formative assessment.

Formative Assessment

According to Black & Wiliam (1998), formative assessment (FA) is such efforts undertaken by both teachers and students in order to modify the teaching and learning process by involving feedback. An assessment could also be formative providing that the evidence elicited is utilised by the teachers to adjust their teaching so as to fit with their students' needs (Black et.al, 2004; Wiliam & Thompson, 2008). However, as I said earlier that providing a circumstance for discussion may support assessing proceptual understanding formatively, thus this essay will apply classroom discussion as a method of FA.

As previously stated, FA is an effort to fill the gap so that the objective planned in the curriculum is attained. In other words, there is a demand for defining or clarifying an intended outcome and compare it with current students' understanding to identify the gap. This idea is relevant with a framework from (Wiliam & Thompson, 2008, p.15) which said FA consists of five key strategies (Table 1).

Table 1. FA Strategies

No	Five Key Strategies
1	Clarifying and sharing learning intentions and criteria for success;
2	Engineering effective classroom discussions, questions, and learning tasks;
3	Providing feedback that moves learners forward;
4	Activating students as instructional resources for one another; and
5	Activating students as the owners of their own learning. (p. 15)

Comparing these strategies to the curriculum defined in this article, strategy 1 is an effort to define the intended outcome. Meanwhile, strategies 2, 4, and 5 aim to analyse where are the students understanding so far. Then, strategy 3 is an effort to filling the gap by giving feedback to students so that they can move from the current level of understanding to approaching the learning objectives. With this relevance, this essay will refer to the five keys strategy for implementing FA.

Furthermore, I acknowledge that the FA strategy from Wiliam & Thompson (2008) is complemented by the approach for classroom dialogue suggested by Hodgen & Wiliam (2006) as listed follows:

1. Promoting thinking and discussion with challenging activities
2. Encouraging students talk by questioning and listening
3. Supporting all students to engage in discussion
4. Organizing peer discussion between students

5. Organizing rich and open whole-class discussions (p. 2)

I see that this approach provides more specific suggestion in how to engineer an effective classroom discussion (FA strategy 2). Hodgen & Wiliam (2006) believe their approach can encourage students to discuss, express, and argue about their notions that can be used to assess ideas and concepts of mathematics of the students. Encouraging open discussion is crucial to create effective formative feedbacks. The feedbacks may not only come from teachers but also the students themselves which support FA strategies 3, 4, and 5. Hodgen & Wiliam also claim that in the discussion, feedbacks may come from three activities. First, feedbacks may come from students when they listening and commenting on other students' ideas. Second, feedbacks can be a reflection regarding activities that have been done. Last, students who give advice to others about the cause of errors and how to avoid it is also called feedbacks.

Nevertheles, Quyen &Khairani (2016) comes to challenge the idea of implementing FA with regard to the classroom context in Asia. Quyen & Khairani said that Asian students often refrain from questioning because they feel shameful to ask if they were uncertain about the answer. I personally acknowledge this challenge also happens in Indonesia. Not only questioning, some Indonesian students also do not confident enough to answer a question due to incorrectness. Despite the need to encourage students to talk in the classroom discussion, I see that the challenge Indonesian students have may be overcome by providing supportive circumstances to enhance question-and-answer activity in the class. Referring to Black et al. (2004) work, they presented a teacher's efforts which is successful to improve question-and-answer dialogue in the classroom such as: 1) questioning, asking students to answer a question and give them time to explore their answer is more interactive is prioritised over presenting how to find solutions; 2) no hands up, unless specifically asked, students are encouraged to put their hands down even they know the answer of a question, also they are expected to give their voice even it is an "I don't know" answer; 3) supportive climate, students are encouraged to be comfortable although they give a wrong answer because they know that it can be useful to the rich of discussion. Considering the FA-keys strategies from William & Thompson (2008), I see that the three efforts from Black et al. are relevant with the FA strategy 2.

Furthermore, in order to create the supportive climate, involving the idea of interpretive listening (Hodgen & Wiliam, 2006) may be helpful. Interpretative listening means that instead of listening for the correct answer, teachers are encouraged to listen to what students think by letting students respond in the way they had. By doing so, in my opinion, students are not over-obsessed with the right answer yet they will be triggered to express their thinking.

Another aspect considered to plan classroom discussion is the type of questions that should be asked to students. Some types of questions could be explored from Mathematics Inside the Black Box (Hodgen & Wiliam, 2006) as presented follows:

Table 2. Type of Questions for Classroom Discussion

Reflective questions	Generic Questions
- "What are the advantages and disadvantages of the method?" - "What is similar…what is different about the ways of solving problems?" - "Did you find one method easier than another?" (p.6)	- "Tell me about the problem. What do you know about the problem? Can you describe the problem to someone else?" - "What is similar…? What is different…?" - "Do you have a hunch? …a conjecture?" - "What would happen if…? Is it always true that…? Have you found all the solutions?" - "How do you know that…? Can you justify…? Can you prove that…?" - "Can you find a different method?" - "Can you explain…improve/add to that explanation…?" - "What have you found out? What advice would you give to someone else about…?" - "What was easy/difficult about this problem…this mathematics?" (p. 9)

Reflective questions provide opportunities for students to think which is important to activating students as the owner of their own learning or similar to self-assessment. Reflective questions allow students to see throughout the process they have done. I suspect the idea of reflective assessment is quite similar to the meta-question presented by Mason (2002). According to Manson, meta-questions are questions that make the students aware of the process by drawing their attention more broadly towards a current task. For instance, "What would you have to do next time to answer a similar question?" (p. 3) and "What led you to choose this approach?" (p. 3). Hence, for the purpose of activating students' self-assessment, I will use both reflective questions and meta-questions as two aspects that complement each other.

Nonetheless, another challenge to implement FA in Indonesian classroom arises due to the class size. Commonly, the class consists of more than 30 students. This condition is also admitted by Quyen & Khairani (2016) who claim that

> *As formative assessment focuses on improving individual student learning based on relevant feedback from different students' needs. A larger number of students per classroom would make it more difficult for the teacher to implement formative assessment. Teachers need to spend more time and attention in order to provide feedback. (p. 167)*

Answering this challenge, connected classrooms can facilitate teachers to do FA more effectively. Hence, let us now consider the literature on connected classrooms which will be discussed in the following section.

Connected Classroom

According to some researchers, the use of technology can support the effectiveness of FA, in this case, a connected classroom is considered as a potential tool to promote FA (Shirley & Irving, 2014; Irving, 2006). This claim is also supported by Roschelle et al (2004) who said that connected classrooms help teachers to collect, manage, and analyse data that have turned retrospectively greatest obstacles becoming easier.

Connected classroom (CC) is a classroom that is designed to be interactive by using a personal computer or hand-held device (Irving, 2006).

Likewise, Roschelle et al (2004) with their term networked classroom explained that in a networked classroom, learners use devices that are connected to the teacher's devices, so that all of the devices can be connected to a shared screen which is displayed in the classroom using a projector for example. Hence, I will see these ideas from Irving and Roschelle et al as a reference for the connected classroom definition in this article.

Turning now to the use of CC to support FA, according to Cusi et al (2017) technology has three functionalities in this respect. The three functionalities of the CC are in line with the five strategies of FA mentioned earlier and I will show the relation in the bracket. Firstly, the CC can help in sending and displaying files, messages, or documents which then assist communication among teachers and students (FA strategy 2). Secondly, the CC can help teachers to process and analyse data that are collected during the lessons (FA strategy 2). Lastly, the CC can provide an interactive environment in which students can work whether individually or in a group (FA strategy 2, 3, 4, and 5).

I admit that engineering discussion within a connected classroom will be helped by the activities of sending, displaying, and analysing which can be less time consuming. Moreover, students will still have a copy of their work submitted. If we compared to a traditional classroom, the students who submit their work in a paper will not have a copy of it since it will be handed to the teacher. Therefore, if the works are discussed in the class, the students cannot directly reflect on their answer which will affect activating students as the owners of their own learning (FA strategy 5).

On the other hand, Beatty & Gerace (2009) established technology-enhanced FA (TEFA) to help teachers in implementing FA by introducing the question cycle. Aided by a Classroom Response System (CRS), TEFA is an iterative cycle of questioning, answering, and discussing. The essential phases of the cycle are presented in the Table 3. I see that the phases complement the approach of classroom dialogue discussed before from Hodgen & Wiliam (2006) as well as the three functionalities by Cusi et al (2017). I will show their connection in the Table 3. Because TEFA is a phase, I put it in the left so that it will not be interchanged while others can be adjusted to the order of TEFA.

Table 3. After reviewing some literature, in the following section, I will bring some key notions from the literature which I will consider to develop a teachers' guidance in doing formative assessment.

The essential phase of TEFA (Beatty & Gerace, 2009)	**The approach for classroom dialogue (Hodgen & Wiliam, 2006)**	**Three Functionalities (Cusi et al, 2017)**	**Description**
1) posing a challenging question or problem to the students	Promoting thinking and discussion with challenging activities	Sending and displaying	I see them as similar processes because I will promote discussion by posing challenging problem to students by sending it through connected classroom.
2) having students wrestle with the question until they give a response	Organizing peer discussion between students		In this phase, I will let students wrestle the question with their peer.
3) using a CRS to collect students' response and display it.		Sending	I will use connected classroom to collect the students' answer
4) eliciting as many as possible different responses and justifications from the students		Process, analyze, and displaying	With the use connected classroom, I will process different answers from student before presenting it back to the student for further whole class discussion.
5) designing a student-dominated discussion of the assumption, perceptions, ideas, or arguments.	• Encouraging students talk by questioning and listening • Supporting all students to engage in discussion • Organizing rich and open whole-class discussions	Interactive environment	I acknowledge the similarities between these aspects which have the ultimate purpose of interactive discussion.
6) providing a summary or meta-level comment to students			I would see this phase more relevant to encourage self-assessment for students (FA strategy 5).

Designing a curriculum: Teacher's Guidance to Conduct Formative Assessment

Having discussed five keys strategies of FA (Wiliam & Thompson, 2008) and how to improve question-and-answer (QnA) dialogue (Black et al, 2004) as well as the connection within the Table 3, in this section, I will bring them all together in one table as follows.

Table 4. Framework for Developing Teachers' Guidance

Point	Phase adopted from TEFA Beatty & Gerace (2009)	Approach for Classroom Dialogue Hodgen & Wiliam (2006)	Three functionalities of CC (Cusi et al, 2017)
1)	Clarifying learning intentions and criteria for success *FA Strategy 1*		
2)	Posing a challenging question or problem to the students	Promoting thinking and discussion with challenging activities *FA Strategy 2*	Sending and displaying *FA strategy 2*
3)	Having students wrestle with the question and decide their answer	Organizing peer discussion between students *FA Strategy 2*	
4)	Using a connected classroom to collect the students' answers		Sending and displaying *FA strategy 2*
5)	Eliciting as many as possible different responses and justifications for the responses from the students;		Process and analyze *FA strategy 2*
6)	Developing a student-dominated discussion of the assumption, perceptions, ideas, or arguments	☞ Encouraging students talk by questioning and listening using questions from Hogden & William (2006) and Mason (2002) ☞ Supporting all students to engage in discussion using QnA dialogue 1. Questioning 2. No hand up 3. Supportive climate 4. Listen interpretatively ☞ Organizing rich and open whole-class discussions *FA Strategy 3,4 and 5*	Interactive environment *FA strategy 2, 3, 4 and 5*
7)	Providing a summary or meta-level comment *FA Strategy 5*		

Before I design the teacher's guidance, with regard to the points in the Table 4, I will make a list of indicators that should be considered as follows.

Table 5 Indicators for Designing the Teachers' Guidance

No.	Indicator
1	Determine criteria success of the topic assessed.
2	Posing challenging problem to students by displaying or sending it through connected classroom. Choose problem which can trigger discussion.
3	Let students wrestle the question with their peer and give their answer.
4	Use connected classroom to collect the students' answers by asking students to send their work.
5	Process different students' answers before presenting them back to the students for further whole class discussion. In this case, I will refer to classifying students works then choose some of the works that may provide many feedbacks for the students.
6	Encouraging students talk by questioning and listening interpretatively
7	Use generic questions as hints to encourage the classroom discussion.
8	In the classroom discussion, give more time for students to think when responding a question from the teacher
9	When conducting the classroom discussion, teacher and students together make a consensus such as: no hands up; no correct and incorrect answer, all students can express their thinking
10	At the end of discussion, provide summary and reflection using reflective questions or meta-questions.

In the following section, I will develop teacher's guidance for engineering classroom discussion in order to formatively assess proceptual understanding in solving complex equation. I create the guidance with regard to all of those indicators in the Table 5.

Teachers' Guidance

Activities : Formative Assessment
Topic : Algebra
Sub Topic : Solving complex equations

BEFORE THE FORMATIVE LESSON

A few days before the formative assessment, define the criteria for success to the students and have students complete a task. This will provide you an opportunity to analyse the students' work and find out some kind of difficulties on their work.

- Criteria for success:

  Students should be able to
  1. Recognize a familiar structure of algebra expressions
  2. Deal with a compound term as a single entity
  3. Choose appropriate manipulations to solve complex equations.

Indicator 1

Indicator 2

- The Task
  1. Send this task to the students or display in the classroom using Google classroom

Solve the following equation with one of your friend. Show and explain all your steps.

$$\frac{24+2x}{x}-1=\frac{2x+3}{3}$$

Adopted from: https://www.map.mathshell.org/lessons.php

Indicator 3

  2. Assessing students' work

     Collect students' responses through Google classroom then note about their current level and their difficulties which reveal through their responses.

Indicator 4

  3. Deciding what should be displayed during the open class discussion. This could be from the students' works. Choose the students' works that can give good example of work. The good works can help students to revisit the objective of learning and can provide feedbacks for students who have difficulties. You can also display the works that can present something that should be avoided in solving the problem.

Indicator 5

During the Formative Assessment Activities

In order to do the formative assessment, you should engineer a classroom discussion. First, display something that you have decided before the lesson. After that, together with the students, set some rule for discussion in order to encourage them to engage in the discussion. You should also listen to your students' thinking by letting students respond in the way they had instead of listen for the correct answer. Furthermore, give the students more time to think about their answer. Remember that you should always clarify the learning intentions during the discussion. At the end of discussion, invite students to make reflections towards what they have learned. You can use the rule and question as follows:

Indicator 1, 6 and 8

Indicator 9

- The Rules are:
  1. no hands up
  2. no correct and incorrect answer
  3. all students can express their thinking

Indicator 7

- In order to encourage the student talk, you can use the following questions or you can make improvisation of them:
  - "Tell me about the problem. What do you know about the problem? Can you describe the problem to someone else?"
  - "What is similar…? What is different…?"
  - "Do you have a hunch? …a conjecture?"
  - "What would happen if…? Is it always true that…? Have you found all the solutions?"
  - "How do you know that…? Can you justify…? Can you prove that…?"
  - "Can you find a different method?"
  - "Can you explain…improve/add to that explanation…?"
  - "What have you found out? What advice would you give to someone else about…?"
  - "What was easy/difficult about this problem…this mathematics?"

  (Adopted from Hodgen & Wiliam (2006)

Indicator 10

- At the end of the discussion, you can use this hint to make reflections with the students
  - "What are the advantages and disadvantages of the method?"
  - "What is similar…what is different about the ways of solving problems?"
  - "Did you find one method easier than another?"
  - "What would you have to do next time to answer a similar question?"
  - "What led you to choose this approach?"

(Adopted from Hodgen & Wiliam (2006) and Mason (2002)

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