Incorporating GLH Attitude into Physics-class Improvements with Small-step Method and DCAP-cycle Method

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Abstract

In the form of "Do, Check, Action and Plan" (DCAP-cycle)-evaluation processes, my teaching practice and improvements will be presented. Towards a unified and essential understanding of physics, we have to know students' learning status. First we have to know how to seize students' learning minds and motivate them to learn physics by demonstration (or experiment) and making students look into daily seen physics phenomena, and have successive question-and-answer dialogues with them. Some parts of complex demonstrations pre-recorded as movies are also shown after it to make students' insight more focused. Do part: Based on the demonstration, fundamental formation of basic notion of physics begins through question-and-answer dialogues between a teacher (instructor) and students. Through the dialogues an instructor can sense the students' learning status and decide the effective starting points to teach physics, such as how to introduce main topics and review of already learned (pre-required) materials of past grades. Check part: The evaluation of students is based on midterm and final examinations, which are analyzed in terms of causes of wrong answers. The analysis lead us to find small-step instructions on how they would understand the right notion in a logical order without replacing understanding physics with meaninglessly remembering series of formulae of physics. Action part: After taking questionnaires of students' opinions, I fed back to their opinions and made some concrete suggestions intended for their modification to the right studying attitude. Plan part: I will present next years' instructional design of physics all with my 14 years' teaching experience of physics in conjunction with the results of former Do-Check-Action of experience of teaching physics, reinforcing the pre-required notions. Every small-step instruction is originated from the analysis of students' learning status.

Keywords: *systematic physics class improvements, GLH attitude, small-step method, DCAP-cycle method*

Introduction

It is a long-pursued challenge for every physics teacher to make students properly understand the basic notion (definition) of physics, accommodated with intuition based on experimental experiences (Fujii and Ohno, 2019). This paper includes a review of Fujii (2023) and improvements in terms of some new notions and classifications.

Recalling my physics class experiences when I was beginning to teach physics, I had had two instructional problems. One was a problem of teaching techniques, such as my inability to give students the precise idea of physics as I had intended, and the other was a problem of students' learning procedure in physics such as their difficulty in how to recognize and define a physics notion from a demonstrated physics phenomenon. In other words, the latter is related to the learners' difficulty in forming basic notions of physics. The causes of difficulty come from some aspects: students' poor learning status, such as lack of background knowledge of mathematical or arithmetical notions and lack of daily physics experiences that help intuitive interpretation of physics, and some mental barriers that prevent the perception of phenomena in physics.

Students within the scope of this report range from C (pass)-evaluated students to S (Very good)-evaluated students. In our school (National Institute of Technology, Tokyo College; in short we call it "NITTC", from now on), S,A, B and C –evaluations are recorded as passing final examination students and D-evaluation is recorded as students who are failing to pass. For simplicity, I discuss educational methods only for the successful (from C to S -evaluated) students.

My fundamental educational attitude is based on the advice from my supervisor at the old workplace, that is *"Grow Lower (poorer) and Higher (better) understanding students in the same physics class and at the same time"*, calling this *GLH attitude* from now on. Honestly speaking to realize the *GLH attitude* sounds like a difficult thing to achieve. But with the scope of higher and lower understanding students, the *GLH attitude* makes us examine whether presently taught physics way of thinking is clear enough for students with different levels of understanding physics. Such self-criticizing points of view lead to improving physics classes more intuitively and deeply through dialogues with students. The *GLH attitude* shall take on every method in the daily trial-and-error practice in this paper.

For sustainable improvements in physics class, the Do, Check, Action, and Plan cycle self-evaluation method is appropriate, which is called the "*DCAP-cycle method*" from now on. In general, the method has recently been tried to be used in practical business fields to adapt working staffs to rapidly changing social situations, while the usual PDCA-cycle method is used to improve an ordinary work routine without rapid changing. Therefore, the DCAP-cycle method has the advantage of fitting educations to rapidly changing students in the new era, with some problems on how to learn. Note also that the DCAP-cycle method can be accommodated with trial-and-error improvements.

To incorporate *GLH attitude* with physics education, let us ask "how can we face and release students' difficulties?" The answer is to separate the difficulties into smaller achievable parts, (see Shimamune, 2008). This separation enables students to increase the number of successful experiences and learning motivations, calling this the "*small-step method*" from now on. Besides, the method reduces the mental barrier against considering physics in many contexts, such as experimental settings, meanings, definitions and the laws in physics.

In this report, I will include the present class practice combined with the *GLH attitude*, the small-step method, and the DCAP-cycle method. In materials and method section, we mainly report the "Do"part and then the "Check"part, the "Apply"part and the "Plan" part are explained; in results and discussion section an overview is presented and conclusion follows.

Materials and Methods or pedagogy

To incorporate the *GLH attitude* into daily physics class practice, two aspects (see Fig.1) are necessary; aspect 1: reduction of the students' mental barriers to learning physics itself and aspect 2: careful introduction of physics notions. Although reviewing pre-required materials is sometimes important, they will be discussed later. One theme of a physics course is composed of many pieces of basic notions of physics. To make each piece firmly understood these two aspects of teaching physics are important. In Figure 1, a rough schematic to form a piece of a basic notion of physics is shown.

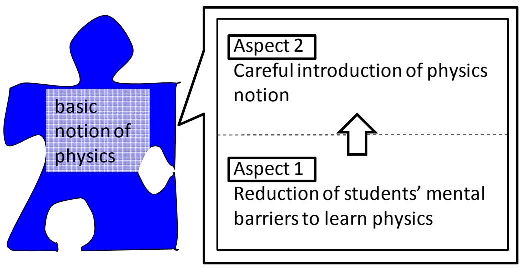

Figure 1.Two Aspects to Form Basic Notion of Physics.

Combining the two aspects obtained by the small-step method, we can gradually introduce concrete materials by confirming students' learning status through dialogues between students and instructor (teacher).

The small steps to realizing each aspect are summarized as follows: for the mental barrier reduction (aspect 1), three small steps can be introduced.

Table 1. Small Steps in Mental Barrier Reduction.
Step1. Intuition formation: expressing notions in words
Step2. Physics situation sharing by demonstration
Step3. Linking intuition and demonstrations

Step 1 is intended for students who are obsessed with an inferiority complex in physics. To reduce their mental barrier to physics, at first expressing a new notion in words can give students its intuitive meaning. Secondly giving daily-life examples corresponding to the new notion is important. Gradually they get used to the setting of physics. Sometimes, we need to choose the simplest and shortest phrase to explain the situations more intuitively. This step is rephrased as "Grab students' minds."

In step 2, after the reduction of mental barrier in step 1, even students who are poor at physics begin to expect to understand physics a little. Then we can go to demonstration. The demonstration is not merely a scientific performance anymore; it has practical meaning for motivated students. The students begin to share the experimental setting and they are prepared to learn the corresponding theme of physics.

In step 3, the meaning of the demonstration can be explained. Now, students roughly see how to extract physics notions from it. Thus, the relationship between the demonstrations and intuition can be introduced. Question-and-answer dialogues with students are good chances to modify some misconceptions, and we can provide feedback of the above steps 1,2 and 3 to them.

For the careful introduction of basic notions by the small-step method (aspect 2), instructions are divided below.

Table 2. Small Steps for Exact Expression.
Step4: Writing down qualitative expressions
Step5: Experimental confirmation of the law
Step6: Linking mathematical expressions (definitions) and experiments

Although the smaller steps of steps 4, 5 and 6 are ordinary teaching procedures in physics, especially in step 4, in order to prepare students to introduce mathematical expressions in physics class, an intuitive approach using schematics is useful. As we have already introduced the relations between notions translated in words, intuition, and experiment in steps 1, 2 and 3, the step 4-procedure now works well.

In steps 5 and 6, after students' experiment they themselves confirm the law of physics. Then the definition, that of physics, experimental results are unified in students' minds as in Fujii and Ohno (2019).

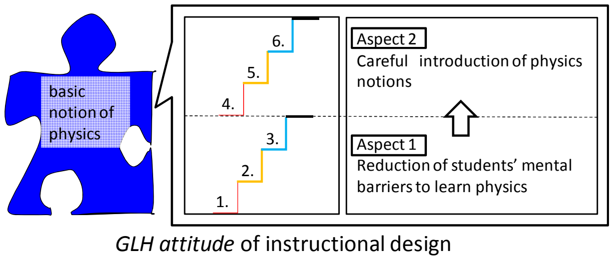

Figure 2. Two Aspects and Each Small Step to Incorporate *GLH Attitude.*

As in Figure 2, understanding the basic notions of physics can be symbolically shown as a piece of a jigsaw puzzle. A collection of the pieces (basic notions) is metaphorically expressed as the essential and "unified" (inter-related) understanding of physics, for example see "trinity of science", (Fujii and Ohno, 2019).

Based on the above methods, we will show the practice of physics in the DCAP-cycle method in the next parts. Before showing DCAP-cycle class practice, let us define "qualitative understanding", as a skill with which students can roughly predict a changing tendency of measured quantities by observation and which can make intuitively grasping phenomena possible.

"Do" part

The number of my physics class practices (90 minutes per class) amounted to 40 in the 8 years' education at NITTC, and my teaching experiences are summarized here. Even for the introductory level of wave physics class for the 3rd grade students, pre-required materials in mechanics should be introduced in addition to the ordinal-instruction model (see Fig.1 and 2). After the mental-barrier reduction (aspect 1, see Table 1), smaller-step instructions (aspect 2, see Table 2) with the review of pre-required materials (see piece 0 in Fig.3) in their necessity, are shown below.

Especially keeping the *GLH attitude*, we aim to have students understand the principles of physics. Such essential and unified understanding of physics can be promoted by linking intuition, definition, experiments and mathematical expressions altogether using question-and-answer communications. In this class, instructors and students both ask questions. Instructors' questions work as an introduction of notions, and ones from students, why- and how-type questions, focus what are essences of the notions. In fact, students' questions range from the confirmation of the present experimental setting, the definitions of physics quantities, to essential questions such as the discrepancies between the laws (or notions) of physics and their naive expectations, leading us to notion-sharpening points of view. The (S, A, B and C-evaluated) students can ask questions anytime in class. This means that regardless of the depth of understanding (or evaluations), many students are able to challenge themselves to understand the principles by asking questions. This is the Q&A-realization of *GLH attitude* in physics class.

To implement the small-step method with *GLH attitude* into a real physics class, we need modifications. As in Fig.3 the modification is to add a "piece 0", the introducing of pre-required materials. With reinforced background notions through the introduction of pre-required materials (piece 0), more students can be ready

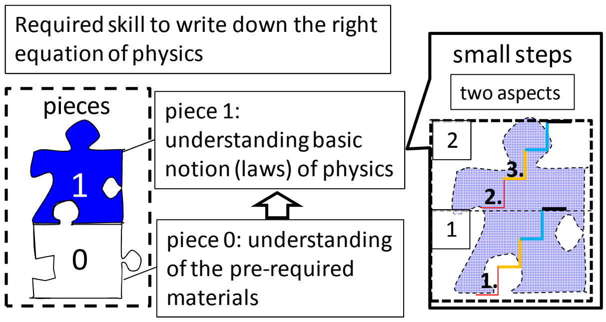

Figure 3. Implementation of Small-step Method into a Real Physics Class (Modification of Fig.2).

for accepting the basic notion of physics (piece 1). And we just follow the ordinal-instruction model; aspect 1:the reduction of mental barriers, and then the aspect 2: the careful introduction of basic notions with the small-step instructions.

Let us show the above implementation in concrete class practice for wave phenomena. As piece 0 (see Fig.3), pre-required materials in mechanics are reviewed, such as equilibrium of applied forces, the equation of motion, uniform circular motion, and harmonic oscillation. And as the aspect 1 in piece 1 (the reduction of mental barriers), a simple circular motion demonstration tool (a tennis ball connected with a kite string) is used as an icebreaker in physics class. Successively, the definition in words (step1 of aspect 1, see Table 1) and its meaning through a demonstration or self-made physics demonstration video for more complex experiments are explained (step 2 of aspect 1). And the link between definition and demonstration is explained (step 3 of aspect 1, see Table 1). A qualitative understanding of physics thus proceeds (see Table 1).

Now that students roughly understand the basic notion, more exact mathematical expression can be acceptable for them. Thus we will go through a careful introduction to build equations of physics properly (step 4 of aspect 2in piece 1, see Table 2). To realize step 4, we can divide step 4 into smaller sub-instructions.

Table 3. Sub-instructions for step 4 (Table 2).

Step 4a: Information classification by schematics
Step 4b:Direction (signature) and unit confirmation
Step 4c:Meaning confirmation by linear graph

Especially, in linear graph of step 4c (see Table 3), the information of slope and intercept of the graph plays a crucial role to check the meaning of equations. Thus, based on intuitive understanding of definition in words (step1 in aspect 1, see Table 1), the schematics-based signature-unit and graph confirmation, the above double-checking of the equation building process is reinforced and students thus can get accustomed to a quantitative way of thinking.

From here, taking the pre-required material, that is equation of motion as an example of piece 0 (see Fig.3), we apply the small-step method into ordinal practice.

Even for pre-required material we sometimes need to apply the small-step method. One is *"translation of equations into words"* (step1, see Table 1). By this procedure, more students would be familiar with equations in physics, so that they could write down equations in physics more precisely without memorizing by rote. Next one is "distinction of quantities based on basic SI system of units".

Newton's equation of motion "mass × acceleration=resultant force", can be translated into a sentence, "When the sum of exerted forces are non-vanishing due to the resultant force remaining, an object with mass *m* [kg] keeps being accelerated in the same direction with the resultant force". With this translation, students begin to understand the meaning of the equation, the purpose of using it and how to use it.

But for students, to be able to write down Newton's equation of motion properly, mere translation is not enough. Problems of misinterpretation of mathematical expressions remain. First the problem comes from the unit in-distinction of forces; the second one comes from the misconception of "*ma*", which is *not* a part of resultant force but *moving state* expressed by unit [N] (Newton) for static observer. And the third one comes from proper direction encoding into signature based on a schematic compared with positive axes directions. Rarely, step 4b needs to be modified as follows.

Step 4b: Distinction of variable symbol and unit name. For example resistance *N*[N], that of *m* [kg] and *L*[m] should be recognized with right pronunciation.

"Check" part

In terms of sustainability of these physics class improvements, it is realistic to make use of usual midterm and final examination evaluations.

In order to evaluate students' understanding of physics class through examinations, description-type problems include much richer information about students' status than multiple-choice problems. We can guess the origin of students' inappropriate logic and can know how deeply they understand the particular theme of physics.

After marking the physics examinations, we can see that most of the students reach the goal in the sense that they can get more than 60% evaluation (C,B,A and S-evaluation) based on the results of examination (75%) and handouts (25%). Class improvements can be reduced to polishing present instructional design[1] with the small-step method and DCAP-cycle method while keeping *GLH attitude*. For the further improvements, after the analysis of description-style examination, students' weak points are found. Then basic review prints are given, and extra question-and-answer class is practiced after-class for the D-evaluated students. Examining the results, they are reflected to sharpen instructional design (plan) in the next year. Additionally, the questionnaire and dialogues as well as their feedback, shall be shown in the next "Action" part.

"Action" part

In this part, we introduce a questionnaire, its analysis and feedback to students, which actually works as a sort of dialogues between students and the teacher (instructor). The questionnaire is composed of multiple-choice questions and a free-style description part commonly taken in Microsoft "Forms" platform in NITTC. In this paper, we focus on the analysis and feedback of the free-description part.

In the questionnaire, "the quantity of physics homework is too much" for many students. This result can be interpreted in as the gap problem between teacher and students. On the one hand, students want to study as *efficiently* as possible, on the other hand the physics teacher wants them to study *effectively*[2] in order to have essential and unified understanding in physics. The necessary instructions range from mastering pre-required materials to enhancing insight into phenomena, relating with law in physics and their mathematical expressions. As I had been worried about their unsuitable way of problem solving since homework checking, I fed back to students as follows:

The purpose of problem solving is *not* merely increasing the number of solved problems, but the reinforcement of the foundation, such as the confirmation of forgotten definitions of basic notions, meaning of the quantities of physics and background in physics and experimental settings. As the second step, the purpose of problem solving is to broaden the range of applications of the laws. As we *cannot assume that every student as the same ability* in physics, we *don't need to do homework in the same way as other students*, which is rather inappropriate to enhance your ability to consider physics. In this way I was able to suggest changing their way of doing homework.

The way of doing homework is summarized below.

Table 4. Small-step procedure for Homework.

Step A: Solve the definition-confirmation level problem first. If having any difficulty, review the corresponding part of the physics text book.

Step B: Pick up some typical and a minimum number of problems. And concentrate to solve the problems as perfectly as possible, including the review of pre-required field of physics.

Step C: After step B is examined enough, then solve similar but different setting problems.
If the basic notion is well established, solving more difficult problems can enhance students' ability.

[1] As referred, methods for growing D-evaluated students are out of the range of this paper, due to much more trial-and-error approaches needed for their analysis.

[2] In most cases, the quality of learning is ignored by "efficiency-oriented" students. *Efficiency and effectiveness in learning are not compatible* practically.

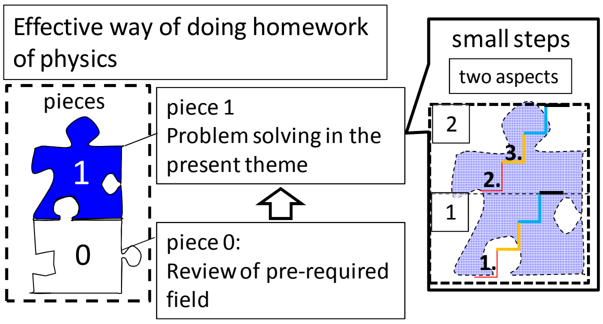

Figure 4. Small Steps for Learning by Homework.

"Plan" part

As the rest of DCAP-cycle method with all the above results of DCA-cycle, next year's physics instructional design are shown below.

Plan: Towards physics class easier and deeper to learn

Steps 1,2 and 3 below aim to forming qualitative understanding of physics notions.

Step 1: Expressing basic notions in words relating daily-seen phenomena, removing misleading (similar) concepts from the students' misunderstood definitions of the basic notions. The translation from equation to words is also introduced as the review of pre-required materials.

Step2: Starting from simple demonstrations, communicate with students on naive questions "why and how?" and their answers by dialogues, forming a rough description of basic notions of physics.

Step 3: Linking intuitive interpretation, experimental experiences (demonstrations) and definitions.

Steps 4,5 and 6 aim at the careful introduction of quantitative (mathematical) expression of physics.

Step4: Make students feel like listening and make use of examples, demonstrations and self-made videos.

Step5: Visualize and define quantities in physics using schematics, graphs and equations, reviewing the meaning and basic SI system of units of the slope and the intercept in a linear graph. Concretely, examining schematics and graph can be small-step instructions, such as the distinction among velocity, acceleration and force vectors, drawing force vector properly with a point of exerted force only on the object, recognizing positive direction of coordinate axes, signature-decoded direction and direction-encoded signature with the positive axes directions.

Step6: Build proper equations of physics, linking relations with experiments, considering deeply.

Optional plan

Steps 1 and 2 aim to cover pre-required material. Introduce them when they are in need.

Step 1: The distinction of units of "similar" quantities

For example, momentum mv[kg m/s], accelerated state ma[kg m/s^2]=ma[N], kinetic energy $1/2mv^2$[kg m^2/s^2]= $1/2mv^2$[J] tend to be confused by students poor at physics. At least the distinction of units can give a good starting point to recognize the differences between these "similar" concepts.

Step 2 : The distinction of basic notions of physics in words by comparison between them.

For example, the word "work" or "force" are similar in Japanese but completely different in physics.

Coaching plan for students (see Table 4, Fig.4)

Following steps A, B and C (see Table 4), below attentions to students are fruitful.

Step 1: Habituation of note-taking in physics class

Step2: Visualization of setting by schematics even during homework.

Step 3: Making the right equation and practice it in homework reflecting on proper logical steps.

Results and Discussion

The separation of single themes of physics into smaller instructional materials, can be a good starting point to attract and reinforce students' learning minds. Combined with question-and-answer dialogues in class and the wrong-answer analysis based on the results of the description-style examination, a more concrete approach can be possible.

Especially, graph interpretation with distinction by basic SI system of units, such as tangential slope and the intercept, is essential because most of the important notions of physics are defined as changing rates.

Conclusions

The student-oriented instructional design are concretely shown in this paper. The answer to the question "How can we grow students in a practical sense?" while keeping *GLH attitude* is, to "start from facing students' difficulties and draw the instructions in need from students themselves. In other words, the *GLH attitude* makes us analyze their weak points in daily-life opportunity and naturally leads us to the small-step method and DCAP-cycle method.

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