# Supporting Students` Conceptual Change in Physics: Utilizing Teaching Strategies from the OGEM Cycle

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Science education research widely supports the notion that in order for students to move from holding naive misconceptions about physical phenomenon toward more scientifically supported understandings, they need to experience some form of conceptual change (Strike & Posner, 1992; Smith et al., 1993; Driver et al., 2000). This study explores the strategies that two experienced high school physics teachers used during whole class discussions to foster their students` construction of explanatory models for electricity. Pre and post-instructional data reveal that, through the construction of these explanatory models, with guidance from their teachers, students` conceptual understanding of electricity appeared to improve. The teaching strategies identified were found to be situated within the OGEM phases of the model construction cycle. This acronym refers to the phases of Observation, Generation, Evaluation, and Modification that students and teachers were found to co-operatively engage in during whole class conversations. It is believed that the strategies used by these teachers contributed to the conceptual change that the students in this study experienced. The purpose of this paper is to describe these strategies and contribute hypotheses as to the particular roles each played in the process of student conceptual change they are believed to have supported.

## Introduction

Science education research widely supports the notion that in order for students to move from holding naive misconceptions about physical phenomenon toward more scientifically supported understandings, they need to experience some form of conceptual change (Strike & Posner, 1992; Smith et al., 1993; Driver et al., 2000). This is particularly true in high school physics classes in which many students arrive with preconceived alternate ideas and beliefs about the way the physical world works (Hammer, 1995; Stocklmayer and Treagust, 1996; Clement, 2008). The question of exactly how teachers can effectively facilitate students` conceptual change is an important one.

This study explores the particular types of strategies that two experienced high school physics teachers used during whole class discussions to foster their students` construction of explanatory models of electric circuits. Pre and post-instructional data reveal that, through the construction of these explanatory models, with guidance from their teachers, students` conceptual understanding of electricity appeared to improve.

The strategies that are identified and described herein were found to be situated within the OGEM phases of the model construction cycle. This acronym refers to the phases of Observation, Generation, Evaluation, and Modification that students and teachers in this and previous studies (Williams & Clement, 2006, 2010, 2011) were found to co-operatively engage in during whole class conversations. It is believed that the strategies used by these teachers contributed to the conceptual change that the students in this study experienced. The purpose of this paper is to describe a sampling of these strategies and contribute hypotheses as to the particular roles each played in the process of student conceptual change they are believed to have supported.

## Study Context and Design

This study was conducted with students and teachers from high school physics classes at various locations throughout the United States. All classes participated in 6-8 week instructional units on the fundamental concepts of circuit electricity. Within the design of the study, the classes were divided into control and experimental groups. The control group was comprised of 262 students who were following traditional instructional approaches (based primarily on didactic teacher lecture and extensive use of quantitative problem solving with a traditional teacher-directed circuits-based lab component in which students experimentally confirmed theory and equations). The remaining 282 students made up the experimental group and were engaged in model-based learning experiences of electricity concepts through the CASTLE (Capacitor Aided System for Teaching and Learning Electricity – Steinberg, 2004) curriculum. The curriculum employs analogies and observations (including discrepant events) as well as the use of analogical physical devices such as syringes, air capacitors and hand-crank generators to translate kinesthetic understanding of key concepts to the learners.

Prior to embarking on their study of electricity, all students completed a 20 item multiple choice diagnostic test of their conceptual electric circuit reasoning and problem solving abilities. The test questions required the students to consider circuits and/or components therein and make predictions about their behavior. The questions asked about situations which were intended to draw out known alternative conceptions. For example, a student reasoning sequentially would tend to predict that the shorting of a "downstream" bulb would not affect the behavior of an "upstream" bulb. Although the CASTLE curriculum involves the use of capacitors, the situations in the diagnostic employed only batteries, wires, bulbs, and single switches, since these were familiar to the control group students as well.

Upon completion of their respective 6 – 8 week instructional units, students in both the control and experimental groups completed an identical post-test. In assessing the gains experienced by students from their pre to post-instruction assessments, a comparison was done to determine whether significant differences existed between the control and experimental groups. It is important to note that the gains described below were calculated using the following two methods:

a) Raw Gain = $\dfrac{\text{(Post-test score – Pre-test score)}}{\text{maximum test score}}$

b) Hake Gain = $\dfrac{\text{(Post-test score – Pre-test score)}}{\text{(maximum test score – pre-test score)}}$

In many well-documented physics education research studies, such as those reporting results of the Force Concept Inventory (Hestenes & Halloun, 1995), Hake gains are calculated in order to determine students' normalized gains from pre to post-test results. Using this method, the gain that students experience is compared to their maximum possible gain rather than to the difference between the lowest and highest possible test scores. Some researchers believe this is a fairer representation of students' growth or change than that provided by a calculation of raw gain. For each type of gain calculation in this study, the results are shown in both fractional and percentage form.

**Control Group (Traditional Electricity Instruction)**

| | | |
|---|---|---|
| Mean Pre-Test Score | 6.59 / 20 | 32.9% |
| Mean Post-Test Score | 7.75 / 20 | 38.8% |
| Mean Test Score Gain (Raw): | 1.17 / 20 | 5.83% |
| Mean Test Score Gain (Hake): | 1.17 / 13.41 | 8.7% |

**Experimental Group (Model-Based Electricity Instruction)**

| | | |
|---|---|---|
| Mean Pre-Test Score | 6.70 / 20 | 33.5% |
| Mean Post-Test Score | 11.61 / 20 | 58.1% |
| Mean Test Score Gain (Raw): | 4.91 / 20 | 24.5% |
| Mean Test Score Gain (Hake): | 4.91 / 13.30 | 36.9% |

Because the assignment of students to the experimental and control groups was done on the basis of locating teachers that either were or were not utilizing the model-based CASTLE curriculum, the selection cannot be considered to be truly randomized. However, the following argument and supporting data provides a rationale for drawing some initial inferences from comparing the groups. Campbell and Stanley (1963) describe this type of study design as a static-group comparison in which an experimental group which has experienced a treatment X (model-based instruction in this case) is compared to a control group which has not, for the purpose of establishing the effect of X. In the absence of randomization, one is left to rely on pre-experimental test results as the only viable indicator of control and experimental group similarity.

In this study, comparison shows the pretest means of the control group (6.59/20) and experimental group (6.70/20) is not significantly different, supporting the null hypothesis that the two groups were drawn from similar populations. The results of these comparisons indicate that it is reasonable to assume that, while not randomly selected, the students in the control and experimental groups, whether taken as a whole or separated by gender, were not significantly different with respect to prior knowledge of electricity or confidence in their knowledge.

Statistical analysis of the results from the pre to post-test comparisons using a repeated measures analysis of variance (ANOVA) with and Alpha value of 0.05 indicated that the students in the experimental model-based classes achieved significantly greater gains than their traditionally instructed counterparts. Additionally, the effect size of the experimental treatment (model-based instruction of electricity concepts) on students' circuit problem solving outcomes is 1.293; a relatively large effect based on Cohen's (1992) scale.

Based on this outcome, the study shifted focus to the task of examining how the teaching strategies in the experimental (model-based) group may have been supporting this growth in students' conceptual development. Of the five teachers from the experimental group, the two whose students' average test score gains were the greatest were targeted for in depth study of their teaching methods. The mean student pre test scores, post test scores, and gains of the students from these two teachers' classes were as follows:

| | Teacher A | | Teacher B | |
|---|---|---|---|---|
| Mean Pre-Test Score | 6.45/20 | 32.3% | 6.73/20 | 33.7% |
| Mean Post-Test Score | 11.80/20 | 59.0% | 12.13/20 | 60.7% |
| Mean Test Score Gain (Raw) | 5.35/20 | 26.7% | 5.40/20 | 27.0% |
| Mean Test Score Gain (Hake) | 5.35/13.55 | 39.5% | 5.40/13.27 | 40.7% |

For this qualitative portion of the study, the data consisted of approximately 30 hours of video recordings and the ensuing transcripts of classroom sessions in which each of the two teachers and their students were engaged in the co-construction of explanatory models of electricity, primarily through whole-class discussions. These large group conversations typically took place immediately following hands-on explorations with batteries, wires, and bulbs that were designed by the curriculum to generate student interest and curiosity.

A grounded theory research approach (Strauss & Corbin, 1998) was selected for the qualitative analysis of this classroom data because of its data-supported ability to generate theories about the effects of certain teaching strategies on the conceptual change students experienced. A constant comparison method (B.G. Glaser & A.L. Strauss, 1967) was utilized in an effort to develop plausible interpretations of teacher strategies that were believed to foster students' construction of explanatory models of electric circuit concepts. This process involved the interpretive analysis cycle of segmenting the transcripts, making observations from each segment, formulating a hypothesized model of students' mental processes that can explain the observations, returning to the data to look for more confirming or disconfirming observations, criticizing and modifying or extending the model, returning to the data to look for more confirming or disconfirming observations and so on (Clement, 2000).

## Results

Analysis of the student/ teacher dialogue from the whole class discussions of the two teachers identified thirty-nine teaching strategies that were believed to support students' positive conceptual change about electric circuits. Although these teaching strategies were utilized within the context of high school physics classes, their descriptions herein are written in a manner such that they can be applied across a broad spectrum of science teaching and learning situations.

Each of these 39 strategies has been catalogued into 21 broader sub-categories, each believed to contribute to one of the 4 OGEM model construction cycle phases mentioned earlier. Examples of ten of these 39 teaching strategies and their categorization within the OGEM Cycle are shown below in Table 1. (For a description of the complete body of 39 strategies, please contact the author at grantw@stu.ca). It is hypothesized that the process of fostering change in students' scientific conceptions requires support from the teacher at various stages throughout the learning process. This can come in the form of scaffolding their explanatory model construction activities at each of the Observation, Model Generation, Model Evaluation, and Model Modification phases.

| OGEM Cycle Phase | Teacher Strategy Sub-Category | Sub-Category Coding Criteria | Specific Teacher Strategy | Example from Classroom Transcription |
|---|---|---|---|---|
| **O** **Observation** | Requesting Patterns in Observations | The statement asks students to reflect on and recall outcomes or results of an experiment. | Requesting students' reflection on experimental observations | T: Okay. How about when you added a second resistor - what did you notice? |
| | Providing Patterns in Observations | The statement tells or reminds students of the outcomes or results of an experiment. | Providing reflection on experimental observations | T: Is that what happens?<br><br>S4: I don't know.<br><br>T: Well what's your evidence that it happens? At some point don't the bulbs cease to light? And the compass ceases to deflect? What's that indicative of? |
| **G** **Generation** | Requesting Explanation | The statement asks students to initiate model construction or explain a general system or a particular element within a model. | Asking students for analogy to initiate model construction | T: You've already seen one analogy about water flowing through pipes. Is there any other analogy you can think of that would explain why this filament would have higher resistance than this filament? |
| | Requesting Modeling Inference from Observation | The statement asks students to generate a model element based on evidence observed | Asking students to generate a model element based on evidence | T: Okay, so same amount. So, what does that tell you about the amount of charge moving through this wire, or the rate of charge movement through these wires? |

Table 1 – Sample Model Construction Teaching Strategies for Promoting Conceptual Change

| OGEM Cycle Phase | Teacher Strategy Sub-Category | Sub-Category Coding Criteria | Specific Teacher Strategy | Example from Classroom Transcription |
|---|---|---|---|---|
| **E** **Evaluation** | Requesting Support for Model | The statement asks students to provide support for a model | Requesting experimental evidence to support a model | T: Okay, there's still charge moving - how do you know? |
| | Requesting Discrepant Result | The statement asks students to refute a model | Requesting experimental evidence to refute a model | T: She thinks that the top bulb should be brighter than the bottom bulb, or lit longer, because she thinks that more charge is going on to the top plate than is coming off the bottom plate. Do we have some evidence that would either support that or refute that? |
| | Requesting that Students Run a Mental Model | The statement asks students to mentally run a model to compare results to experimental data or to make a prediction. | Suggests running a model in a thought experiment and comparing to experimental data | T: What does the resistor do?<br><br>S3: Insulate. It acts like an insulator—<br><br>T: Acts like a good insulator?<br><br>S3: No, because some of the charge still gets through… |
| **M** **Modification** | Requesting Concept Differentiation | The statement encourages students to discriminate between two elements of a model | Asking students to examine the relationship between two elements of the model | T: That's probably true. But is heat the same as charge?<br><br>S6: Charge is like energy<br><br>T: Does charge get changed into heat? Is that what we're thinking? |
| | Requesting Concept Integration | The statement encourages students to integrate one concept into a larger conceptual category | Encourages students to integrate one concept (bulbs) into a larger conceptual category (resistors). | T: Okay, so is there any real difference between a resistor and a bulb?<br><br>S4: No.<br><br>S6: Yeah. The only difference is that you can see the energy in the bulb, but not in the resistor.<br><br>T: Okay, so can we call the bulb a resistor? Or, the filament in the bulb a resistor?<br><br>S6: Yeah |
| | Requesting Refinement – Increasing Precision of the Model and Vocabulary | The statement asks students to provide alternate explanations or repairs to the language describing a model | Asking for alternative descriptions or explanations | S6: I think it absorbed some of the charge.<br><br>T: Absorbed some of the charge. Anybody have anything else? What's another word for absorbs? |

Table 1 – Sample Model Construction Teaching Strategies for Promoting Conceptual Change (continued)

Once the collection of teaching strategies were identified, described, and categorized as to their hypothesized contribution to the model construction process, the next step in the analysis was the development of a diagrammatic flowchart (see Fig. 1) outlining a Generalized Learning Pathway from the point of initial misconception, through the OGEM phases of model construction, to the development of a scientifically accurate explanatory model (the target conception). This flowchart permits the identification of opportunities throughout the learning pathway for particular types of teaching strategies to be employed in the support of students' conceptual change.

For example, the teaching strategy from Table 1 – "Providing reflection on experimental observations", which has been identified as contributing to the "Observation" phase of the model construction cycle, is shown being utilized at the point in the flowchart labeled "Eliciting students' thinking about experimental or everyday observations". Similarly, the strategy, "Requesting students' reflection on experimental observations" is also believed to contribute to the "Observation" phase of the OGEM cycle and is suggested for utilization at the "Exposing preconceptions" stage of the Learning Pathway. Whether the teacher is asking students to recall and then verbalize their own observations of scientific phenomena or instead provides some key words or phrases to help them reflect on what they have seen it is believed that this is an important type of strategy for initiation students' thinking.

In the "Generation" phase of the model construction cycle, the teaching strategies "Asking students to generate a model element based on evidence" and "Asking students for an analogy to initiate model construction" are situated at the "Generation of an explanatory model" portion of the Generalized Learning Pathway. It was observed that these types of teaching strategies are often used at this juncture to scaffold students' transition from identifying their preconceptions to developing plausible explanations for phenomenon. At this stage of the OGEM cycle it is crucial that teachers find ways to help their students construct evidence-based justifications for the phenomena they have observed. The teachers who were observed in this case study exhibited a variety of techniques for encouraging their students to unabashedly engage in this model generation process.

"Requesting experimental evidence to support a model", has been identified as contributing to the "Evaluation" phase of the model construction cycle, and is shown being utilized at the point in the flowchart labeled "Design and running of physical experiments". The conversational teaching strategy "Requesting experimental evidence to refute a model" is placed on the Learning Pathway at the "Discrepant event resulting in cognitive dissonance" stage since it has been observed that teachers employing model-based teaching approaches often introduce demonstrations or explorations designed to generate evidence that challenges student-generated explanatory models that may not align with the scientifically accepted one. Another strategy that both teachers in the study were observed to frequently employ during the Evaluation phase of class discussions was to "Suggest that students run a mental model in a thought experiment to see whether the hypothesized outcome would match actual experimental observations". This strategy of comparing what "would happen" in the case of a proposed explanatory mental model with what "does happen" in the physical case was usually very successful at helping students discard fruitless or implausible models.

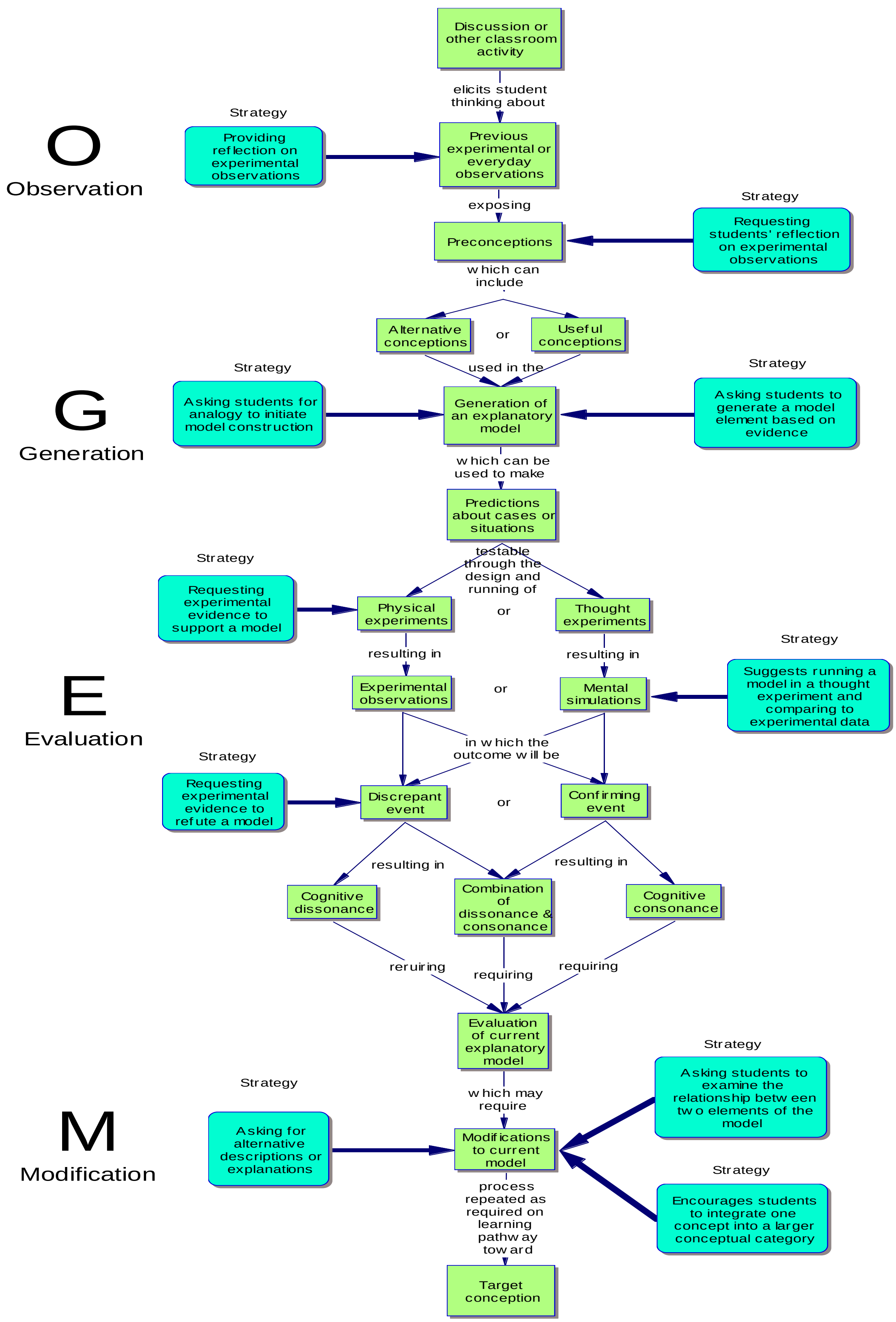


Fig. 1 – Flowchart of Generalized Learning Pathway

In a related study (Williams & Clement, 2008), it was determined that the high school physics students involved in these whole-class model-building discussions were often somewhat reticent when it came to participating in the Evaluation phase of the OGEM cycle.  It is speculated that in the majority of their previous classroom experiences, it had traditionally been the teacher's role to do the evaluating.  The students simply may not have the experience of being asked what they think about models and explanations because in the IRE style classroom model (Lemke, 1990) they may be more familiar with, it is the teacher's role to evaluate the students' ideas. Additionally, through traditional science instruction, it is common for students to develop a view of science as having "one correct answer or idea or explanation". As a result, they may not be familiar with and thus are hesitant to participate in the process of evaluating various ideas or models as a way of determining which explanation makes the most sense (Williams, 2011). Regardless of this initial reluctance to participate in the evaluation of their own or their peers' explanatory models, the teachers in this study utilized a wide range of strategies such as introducing discrepant evidence and encouraging debate to enable their students to do so.

Once students have been provided opportunities to evaluate the explanatory models that have been generated, it has been observed that they often find modifications are required for their models to continue making sense to them as new evidence emerges.  In order to scaffold these model modifications, teachers can use such strategies as "Asking for alternative descriptions or explanations" and "Asking students to examine the relationship between two elements of the model".  On the Generalized Learning Pathway flowchart, teaching strategies such as these are identified as contributing to the "Modification" phase of the model construction cycle and are shown being employed at the point labeled "Modifications to current model".   Another strategy used by the teachers was to encourage students to integrate one concept (bulbs, in the case portrayed) into a larger conceptual category (resistors in general).  In the case of the class discussions featured in this study, this was helpful for fostering students' understanding of light bulbs as resistors, but a strategy such as this would work equally well in a life sciences context for scaffolding students' understanding of crustaceans as arthropods, for example.

It is interesting to note that, by the time they completed their units of electricity study, the majority of students from the classes of these two teachers reported through a post-instructional survey that they viewed the explanatory models they developing as very flexible and changeable and seemed to believe that the modifications that they made to the conceptions in their heads were influenced by the questions, examples, and analogies being introduced by their teacher during their class discussions. This data supports the notion that the conversation strategies selected by educators can influence students' conceptual change.

## Contribution

It is believed that this study's attempts at developing a correspondence between a Learning Pathway Flowchart and the Table of Model Construction Teaching Strategies for Promoting Conceptual Change will contribute to a theory of model-based instruction that connects levels of instruction for researchers and informs curriculum developers on how the structure of a curriculum can support discussions resulting in students' active reasoning.  Also, this study may support the work of teachers and teacher educators by dividing the extremely complex act of science teaching into several basic sets of skills so that the sets can be learned and practiced one at a time.

To this point, there has been little research within the realms of conceptual change theory, model-based teaching and learning, and whole-class discussion-based pedagogy that attempts to situate one within the other in a manner that permits practitioners to understand not only **what** types of teaching strategies may support student conceptual change, but **when** they may best be employed during the teaching and learning process. This study hopes to support this type of further investigation.

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