Model S2 as a Conceptual Support for the RSA

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ABSTRACT

The double role of gravity (DRG) presents a known conceptual challenge when using the Rubber Sheet Analogy (RSA) to teach General Relativity (GR), as described by many scholars. This challenge may lead to difficulty for students to accept GR as a meaningful theory and may affect their confidence. Since attitude is considered crucial for conceptual change (as proposed in the DMCC framework), such confusion may also influence students' motivation and engagement with the subject. The DRG can be resolved if the curvature in the RSA is removed; however, this would make it difficult to demonstrate how a planet moves - similar to the motion of a planet orbiting the Sun. To support the RSA and reduce this issue, we propose introducing the Smz-Table Model (Model S2) earlier in the learning process. Model S2 is proposed to support the development of Awareness 1 (A1) and Awareness 2 (A2), which may better prepare students for interpreting both the RSA and GR. By introducing Model S2 before the RSA, students may build a clearer conceptual foundation, and the combination of A1 and A2 may help reduce misconceptions and support understanding when the RSA is later demonstrated. Note that the RSA is already used internationally and is likely to become a standard tool for illustrating GR concepts. Previous studies suggest that many students find GR interesting. Reducing RSA-related learning difficulties may improve its acceptance.

Keywords Pre-university Physics, High-School Physics, General Relativity, Physics misconception, Physics Model Analogy, Conceptual understanding, Rubber Sheet Analogy (RSA)

INTRODUCTION & MOTIVATION

The groundbreaking discovery of gravitational waves was officially announced on February 11, 2016, by US LIGO scientists. Although the detection occurred in 2015 [1], the detection followed extensive checking to ensure precise confirmation. This discovery provides significant direct proof of gravitational waves, complementing numerous previous tests that validated related theories.

In the physics educational world, inspirational educators constantly seek a way to introduce fundamental concepts, such General Relativity (GR), to students. Basic GR, which is predicted to be taught at a level such as higher education and university degree foundation programs, especially in developing countries where GR is not yet part of the standard curriculum (possibly starting with aerospace programs).

The relevance of Special Relativity (SR) and GR extends beyond theoretical physics into practical space applications, such as GPS systems, which affect all modern civilizations that use GPS [2]. These issues are significant and cannot be ignored [3,4]. GPS systems move very fast and have significant gravity differences from the surface of the Earth, which requires estimations of calculations based on Einstein's new theory, making it impossible to use Newton's old theory. This highlights how important it is for GR and SR be understood by new generations.

However, compared to Quantum Mechanics and SR, which have already made their way into secondary and undergraduate schools in many countries, the theory of GR has only recently made its first attempt to enter the school curriculum and investigate its comprehensibility [5]. For this reason, this paper aims to contribute to the ongoing efforts to introduce GR into the curriculum.

Problem Background

Most school students have reported finding General Relativity interesting [6]; similarly, Special Relativity has been identified as one of the more interesting topics among physics subjects in another study [7]. These findings suggest a general positive interest among students toward relativity concepts, even though they are often perceived as advanced topics within physics education.

While the original mathematics of GR is said to be very difficult, the conceptual aspects are likely moderate and engaging. The mathematics of GR may not yet be suitable or ready for secondary or high school students to learn [8, 9], based on the current understanding of this issue. Therefore, educators should be encouraged to use a conceptual approach in teaching this concept of GR [10,11], again, from the present perspective. Thus, the mathematical complexity may need to be replaced with several accessible methods, serving as a bridge to make the concept acceptable but still superior. The goal is to introduce the physics concept first and then address the more complex mathematical aspects later.

As the research on General Relativity (GR) in schools is still in its early stages and developing [12], the increasing integration of relativity concepts into the curriculum makes physics education more essential than ever. This growing emphasis on relativity has highlighted the need for careful teaching methods or models to prevent misinterpretation [13]. As a result, physics education has become an increasingly fertile field of research [13]. Therefore, the introduction of new methods: Smz-Table Model (Model S2) to facilitate the most commonly used models worldwide (still in used but still got problem) is strongly recommended.

The educational community, meanwhile, has begun to explore the most appropriate ways to introduce this new gravity theory (GR) into the classroom [8]. In some countries where the syllabus for GR at the school level has not yet been finalized, there is an opportunity to develop a more effective educational research plan (potentially addressing common issues or local problems).

To describe GR indirectly, Einstein's new theory of gravity was usually described using a “trampoline” (RSA) by educators or instructors, with a heavy ball in the middle and light balls around it. The trampoline is like a rubber sheet model, and something like this rubber sheet is occasionally called a spacetime simulator [14] or pillow model [15]. Although the model is said to be very good, what is worrying is if there is any instructor who might give an explanation of using the trampoline in such a “straightforward” way for the first time since the method also, in fact, uses the old concept of gravity incidentally; therefore, it probably confuses students in the end, and even raises questions such as why we use gravity to explain how “gravity” actually works. The problem is raised as “Double Role Gravity”, as [16] carefully discussed it as the number-one problem besides other issues.

While such a model can facilitate a difficult theoretical understanding, it is believed that it has the potential to lose the appreciation of some students. This is because, in general, something oversimplified will erode the value of appreciation for the subject; in addition, there may be a slightly uncomfortable feeling hidden behind it (students may think about it and may prefer to remain silent in honor of their teacher).

The theory of General Relativity is said to have been packaged in mathematical form [17], a process that is not straightforward. A noteworthy comment from a scholar [5] about the RSA, in relation to Russell’s work, is as follows: “Interestingly, at the same time Russell cautioned of the risks of simplifying scientific ideas too much: ‘Einstein revolutionized our conception of the physical world, but the innumerable popular accounts of his theory generally cease to be intelligible at the point where they begin to say something important’ - a wise remark that foreshadowed the debate around the rubber sheet analogy (RSA) that scientists and educators still lead today” [5].

The issue could be potentially “misleading” or cause problems for some students, whereas brilliant students or any potential moderate students are hopefully able to continue Einstein's work one day. Beside the profound discussion by [16], other detail positive and negative aspects have also been highlighted seriously by scholars

[5] in a topic about the role of the rubber sheet analogy in learning GR. Furthermore, if the method ends with a feeling of dissatisfaction or eventually the student underestimates the method, then the subject of physics itself may be affected.

Most science instructors have probably underestimated the extent to which the concepts perceived by their students differ from the concepts of science that have been taught [18]; this suggests that the previous statement is likely to be correct. Perhaps, what a physics teacher doesn't want: Potential students (good students) eventually distance themselves from subjects such as physics or science (or special topics like GR).

Again, in Einstein's theory of GR, the spacetime curvature is an important concept that is difficult for any educator to explain. The spacetime curvature causes an object to move along the nearest straight line, where a straight line in a curved spacetime makes an apple 'fall' to the ground. A good visual model has been demonstrated by [19], however, to associate something flat with a curvature is a difficult one as well. To assist the instructor in this regard, in the presentation of this paper, there is a clear analogy approach to the meaning of the Newtonian field curvature according to Newton's theory. It could be introduced before the teacher or instructor introduces the RSA as described in subsequent sections.

Exploring GR Education: A Fresh Perspective from The Smz-Table Model (Model S2) Supporting RSA

This section introduces the theoretical framework and concept development underlying the Smz-Tabletop Model or simply Model S2, demonstrating its potential to supporting the RSA model. Fig. 1 shows the commonly used graphical model and trampoline (representing the RSA model) as a representation of Einstein's gravity concept. Then, if an object of heavy mass is placed swimming somewhere in the universe, the spacetime around the object is distorted.

(a) (b)

Fig. 1. GR teaching and learning (a) Conventional graphical model (b) Example of trampoline (representing the RSA model).

Before students try to understand how a straight line in curved spacetime causes an apple to fall to the ground, they may look at an example of a real case involving a potential energy difference. From there, the idea of a curvature gradient may become more intuitive when interpreted on a surface that appears flat.

The instructor can guide the students to compare the two situations shown in Fig. 2(a) and Fig. 2(b). In Fig. 2(a), the ball rests on the flat tabletop, where the direction of the gravitational force is perpendicular to the table, acting uniformly vertical downward, balanced by an equal and opposite normal force. Therefore, the ball cannot move anywhere (remains stationary).

However, in Fig. 2 (b), the surface is inclined. Here, the gravitational force vector and normal force vector are not completely opposite (not totally aligned in one line). As a result, there is a component of force leading to the left of the table, causing the ball to move down the incline (ignoring friction).

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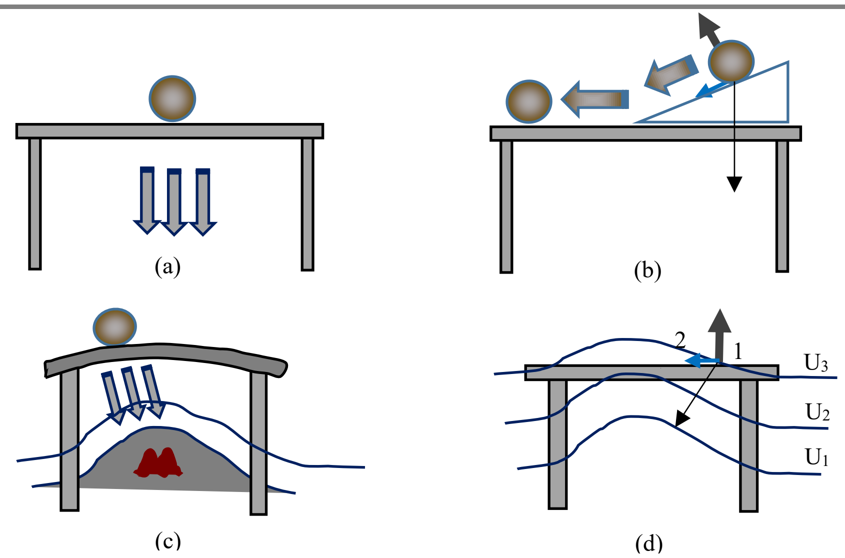

Fig. 2. The Smz-Table Model (Model S2) represents the curvature from Newton's theory. (a) Equilibrium condition. (b) Object moves to the left. (c) Object on the same potential line. (d) Newton's curvature exists on the flat surface.

In the second stage, the instructor can bring the students' attention to the mountains that have very dense masses, as in Fig. 2(c). Since the mass distribution is no longer uniform, the effective gravitational field at a given point may vary in direction, as illustrated in Fig. 2(c).

This can be described as a blue (curved) line in Fig. 2(c), which describes the same level of energy line (equivalent potential). The practical meaning of this blue line is that, if a ball is placed at any point on the blue line, it does not roll anywhere (to right or to left, if being supported along the blue line as well). Assume that because of the very dense masses, the potential line no longer approaches a straight line, but instead follows the shape of the blue curve.

Therefore, if a large table is said to have been made on a mountain (a large building), then the designer of the table (a concrete building), within this analogy, may follow the curve of this new potential energy line as guidance, as shown in Fig. 2(c). As a result, if a ball is placed at any location on the table, it may not be able to roll easily (assuming a one-dimensional table surface). If the designer who built the table was unaware of the curvature of the potential line, then a flat-shaped table might instead have been built. In this case, the table may exhibit an apparent phenomenon, where an object placed on a particular surface appears to move on its own.

For instance, if the same ball is placed at position 1 (as shown in Fig. 2(d)), then it is able to move from position 1 to position 2 because there is a force component acting to the left. This situation is very similar to that in Fig. 2(b), which can be interpreted as a form of "Newtonian curvature", in which the condition is actually flat (although the flat representation is not explicitly shown in the usual sense). If observers are not aware of the characteristics of this effective Newtonian field representation, they may interpret the motion as being caused by an additional or "hidden/strange" force. Thus, in the coordinate representation of the table system, which appears flat, there exists an effective curvature interpretation in terms of Newton's gravitational field.

Thus, by this analogy, it may be easier for instructors to explain to their students that, although the coordinates of this experienced space appear flat, there is yet another meaning of curvature that Einstein referred to as "spacetime curvature." However, it is indeed not directly visible - only the effects of the curvature can be observed. Note that this phenomenon is described only for illustrative purposes, and Newtonian curvature is not the same as Einsteinian curvature.

In the real world, the lines that appear curved on the mountain would not look very significant or have sharp turns; instead, they are intended merely to illustrate the underlying principles. However, basically, such a situation is possible if the underground density is highly uneven. In geophysics, the related phenomenon is called a gravitational anomaly. The potential line of gravity is supposed to be called the equipotential surface (if in 3D world). Moving a mass from one point to another on this surface is considered "no work done." The absence of matter (a large hole or lower dense of object) below a land area gives rise to a negative anomaly, whereas the presence of a very dense object gives rise to a positive anomaly [20,21,22].

Certain locations around the world exhibit mysterious gravitational anomalies, and northern Cameroon is a particularly active area for research. Various studies have explored the gravitational anomalies in this region, reflecting the area's geological complexity including volcanic activity [23,24,25,26]. However, publicly available materials for high-impact teaching, such as photos and videos, are often limited. Nonetheless, studying these gravitational anomalies is valuable for understanding how variations in underground mass influence gravitational fields. Even if real-world examples are not visually striking, they provide good analogies for understanding spacetime curvature. This deeper understanding can help instructors effectively illustrate concepts in GR.

What Is the Model S2 Expected to Deliver?

Model S2 is expected to reduce some of the negative effects of the RSA and help in some way, as described in the paragraph below.

First, students may be guided to recognize the notion of an effective Newtonian curvature, even though the surface appears flat. In Newtonian gravity, as illustrated in Fig. 2(d), units U1, U2, and U3 may be used to represent different levels of the equipotential line, or more generally an equipotential surface in three-dimensional space. This representation can be understood as an effective structure arising from uneven mass distribution on Earth. Although it cannot be directly observed, it plays an important role in describing gravitational behavior within this framework.

Second, the object may be described as moving in response to the effective Newtonian curvature. The student may relate this idea in the following way: if the potential at point 2 is lower than at point 1, the ball may move toward point 2, as shown in Fig. 2(d). This provides an intuitive explanation for why motion can occur on a surface that appears flat, giving an indirect understanding that the RSA does not need to be explicitly drawn as a curved surface. The bending in the RSA represents the "Einsteinian curvature," which is also not directly visible. For example, the motion of the ball shown in Fig. 1 (GR model) is attributed to spacetime curvature.

If the first and second points provide students with strong cognitive reasoning, the third point concerns attitude. Student attitudes are expected to improve, as every detail in the Smz-Table Model is logical and makes sense. The reasoning is suit enough to address the issue of 'Double Role Gravity' as raised by scholar [16]. Here, the main potential issue: the math is tough, and the curvature of spacetime is really difficult to imagine. Then, the RSA analogy (the best model we currently have for visualizing the theory), adds its own challenges as well, as discussed in Section 2.

An example was used to demonstrate an RSA practical session (Fig. 4, as discussed in [16], with the video accessible via the link provided in Appendix 1). This example illustrates how the RSA is commonly presented in classroom practice, and it highlights the instructional context in which higher level students engage with the model.

Because the feature of Model S2 is unique, if it can be clearly visualized, it is expected to help reduce misunderstandings in both short-term and long-term memory, as visual representations are often more easily retained. This may be particularly useful in addressing misconceptions associated with the RSA model. However, a more complex model may also increase cognitive load, and therefore, within the framework of cognitive load theory, certain considerations should be followed [27]. For example, it is important not to introduce both models simultaneously, but instead to ensure that one concept is sufficiently understood before progressing to the next, so that the effectiveness of both models can be maintained. The Model S2 is therefore intended to be introduced first as prior knowledge before transitioning to the RSA model.

Model S2 can help instructors present the concept of spacetime curvature using RSA in a way that is more academically appreciated and intellectually satisfying.

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DISCUSSIONS

Educators and researchers are encouraged to explore the contributions of the Model S2 and document their experiences and outcomes. By actively engaging with and testing the model, the academic community can drive further improvement and innovation in GR physics education, ultimately enhancing teaching pedagogy and student understanding. However, depending on the education system and syllabus, students must first be familiar with Newtonian gravity for smooth transfer learning.

Back to the trampoline problem, the Model S2, if introduced correctly, could lead to a more meaningful understanding and connection with the RSA model - increasing students' confidence in phenomena that exist but cannot be directly observed. Reasoning with abstract content tends to be more difficult for students around the teenage years [28], employing concrete learning models could make the concepts easier to grasp.

If this is achieved, the physical models used to represent the GR concept, as shown in Fig. 1, may be better appreciated by students. If the issue of “Double Role Gravity” [16] can be addressed through the Model S2, it may help reduce uncertainty regarding the use of the RSA model as an instructional tool for teaching GR concepts.

Another target is the students' attitudes. According to [29], attitude is a key element in promoting conceptual change for students. They proposed the Dynamic Model of Conceptual Change (DMCC), which built on previous models and emphasizes attitude as a central factor in driving conceptual change [29]. By addressing and controlling common misconceptions (which often cause confusion and uneasiness), this approach could lead to an improvement in students' attitudes - because a clearer, more logical flow of concept should make learning feel more intuitive and engaging. As attitude is understood as the overall value that students assign to an object or subject [29].

Previous research suggests that students’ attitudes may influence three aspects of learning: cognitive processes, affective (emotional) responses, and behavioral tendencies [29]. Therefore, Model S2 is expected to support these three components as well. In the DMCC framework, emotion and affect are distinguished, and in this paper the original DMCC model has been simplified to highlight the most relevant elements for GR education research. These components are represented in Fig. 3 using symbolic representations, which provide a visual illustration of how Model S2 may support understanding within the RSA framework. This may contribute to facilitating conceptual change.

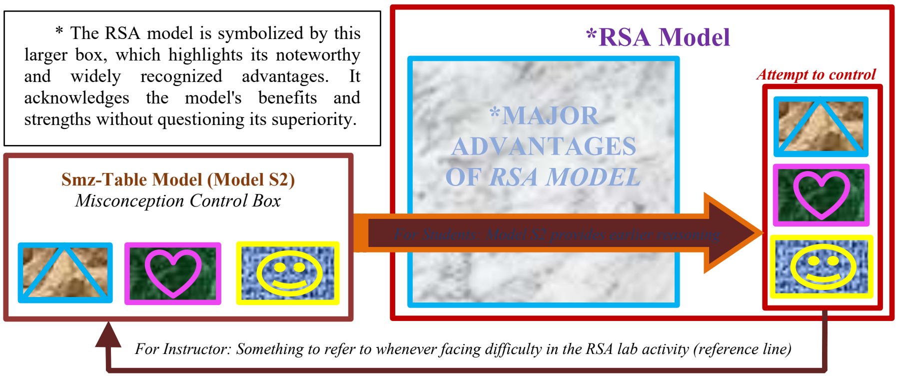

Fig. 3. Graphic model of how the Smz-Table Model (Model S2) could help misconception in the RSA Model.

Besides that, for the instructor, this Model S2 also offers a "misleading control" line which can be seen as ‘reference line’ in Fig. 3 - meaning the instructor might have some answers to refer to whenever facing difficulty while demonstrating the RSA.

In learning models such as the RSA as well as other models, all of that can be considered a useful learning analogy that can be practiced by educators. However, it is important for educators to formulate the various analogies (models) and cross-examine (understand the limits) each of them [30]. Thus, in general, even though the constructive mental model approach in this article could help the existing model, readers and researcher must realize that there is a possibility that it also has its own advantages and disadvantages as well as their limit, if viewed from another angle (for future studies).

Perhaps new ingredients, such as the Model S2 in this paper for the standard RSA analogy, can complement the standard science education map and improve the well-formulated things [31] (Mat Said et al., 2020). Other specific and general issues are still open to researchers to meet the challenge of this new GR education research area; for example, the analogy of time distortion is still missing to help the RSA model. The Smz-Table Model, also represents an effort aligned with the comprehensive study of the DMCC - outlined by [29].

Summary - Final Reflection

One, in this educational conceptual paper, the Model S2 reveals the possible existence of the Newtonian curvature, which can be perceived theoretically and appreciated.

Two, the model demonstrates how objects can move on a 'flat' surface, where Awareness 1 (A1) describes the observable motion behavior, while Awareness 2 (A2) represents the hidden 'curvature', and both work together as a combined interpretation, offering a clearer understanding. This dual awareness is intended to assist instructors in moderating potential confusion or misconceptions that may arise during RSA sessions, particularly addressing the issue known as "Double Role Gravity" [16].

Three, the model is also intended to address some of the subtle discomfort that students, especially mature students, may experience when using the standard RSA model. This aspect has been mentioned in the Problem Background section and is linked to non-verbal cues observed during a laboratory activity (see Appendix 1). Thus, the introduction of Model S2 may support student engagement and improve understanding during RSA model demonstrations.

Four, attitude is represented as an important component within the DMCC framework [29]. By addressing negative attitudes toward the RSA model (through misconception control), Model S2 may support the reduction of confusion and contribute to a more positive learning experience. This perspective highlights the role of psychological aspects in teaching complex concepts such as GR.

Five, the idea of a model that supports another model can be seen as an additional instructional approach within conceptual physics education. The support provided by Model S2 to the standard RSA model (which remains widely used internationally) can be compared to preparatory learning approaches, such as game-based learning, before engaging with more formal physics content. While the physics concepts themselves remain unchanged, such preparatory approaches may help improve students' engagement and interest in the subject. This is consistent with findings that game-based learning can support understanding and motivation in physics education [32]. From the perspective of the DMCC framework [29], this approach may also be relevant in supporting student attitudes, which are considered important in conceptual learning processes. Overall, this suggests possible implications for instructional design in physics education.

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