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Research Article

Physics teaching via dialogic discussions about circus activities

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ABSTRACT

Circus art excites amazes and delights. Most of circus genres are based on the principles of classical physics. Dialogic discussions are known as an instrument to identify conceptual barriers (misconceptions) and facilitate their further revision. The present study integrates the three worlds: physics education, dialogic teaching and circus art; and provides a research foundation for experiential physics teaching through dialogic discussions about circus tricks (DDCT) in formal and informal setups. It aims at examining the potential of DDCT as a tool for identifying misconceptions and facilitating conceptual change regarding physics concepts. The study encircles about 40 DDCT provided in the Israeli KESHET circus. In total, about 5,500 people watched the shows. From them, about 400 actively participated in the DDCT. We analyze in details four typical DDCT relating (a) circular motion, (b) moment of inertia, (c) torque, and (d) heat transfer. For each DDCT we demonstrate the way it pinpoints participants' knowledge and its implementation in circus devices' analysis. Further we examine whether and how the DDCT could facilitate developing physics knowledge and/or going through a meaningful conceptual change regarding each of these concepts. Due to our results DDCT seems to be an original and promising approach to bring advanced physics ideas to the general public, in ways that are interesting, experiential and relatively easy to understand. We finish with practical recommendations for physics educators (as well as circus artists) who would like to implement DDCT in their classes (shows).

Keywords: physics education, dialogic teaching, informal teaching, misconceptions, conceptual change, circular motion, moment of inertia, torque, heat transfer

INTRODUCTION

Circus art "excites, amazes, and delights" (Gurevich, 1977, p. 1). It captures the imagination of most children as well as adults bringing to audience the human beauty, courage and passion, glitter, and glamour; making the spectators to laugh and to worry, to feel, and to think intermittently. Most of circus numbers[1] (in the basic genres such as acrobatics, equilibristics, juggling, etc.) are based on the principles of Newtonian mechanics. Fire shows can be explained in the terms of classical heat theory; illusion usually applies the principles of classical optics and psychology. The idea of employing certain circus numbers and/or single tricks to illustrate physics principles is not new. For instance, Perelman (1994) in his classical "Entertaining tasks and experiments" as well as, Halliday et al. (2014) in "Fundamentals of physics" present the example of a bicycle

[1] Classical circus shows are composed of relatively short parts. Each part usually presents a different art (acrobatics, juggling, equilibristics, etc.) and called a number. Certain exercise in a number is called a trick.

rider performing a dead loop to illustrate the laws of circular motion. "Fundamentals of physics" (Halliday et al., 2014) also illustrate tension and the second Newton law in a problem relating an aerial gymnast performing on a rope (cord-de-parel); and energy conservation law in another problem analyzing a sliding of a performer on a pole. Science circus visindi (Schlender, 2013, video reportages about the show are available at: https://www.voanews.com/a/scientist-circus-performers-make-physics-fun/1632653.html; https://www.facebook.com/pg/Visindi/posts/) went even further and built a complete show which brings the basic concepts of Newtonian mechanics to the general public in ways that are relatively easy to understand even for those without a physics background. Yet no research attempt was made to investigate the possible contributions of pedagogic setups anchored in circus art to physics education.

Looking at children and adults' faces amazed by circus performances, one can obviously expect that experiential teaching (AEE, 2011; Gorghiu & Ancuța Santi, 2016; Young et al., 2008) of physics concepts employing circus environment is of a potential to result in pedagogic outcomes, which formal frontal classes are found difficult to achieve. Indeed, numerous studies report the presence of robust misconceptions regarding physics concepts even after a thorough teaching process (for instance, Chi et al., 2012; Demirci, 2005; Ding et al., 2013; Eshach & Schwartz, 2006; Hestenes et al., 1992; Roche, 2001; Vyas, 2012). Furthermore, our previous studies conducted on university students and graduated engineers show that even after completing learning, participants have difficulties in applying theoretical knowledge to explain physical phenomena in real life, for instance, how simple devices work (Ben-Abu, 2018; Ben Abu et al., 2018; Volfson et al., 2018, 2019, 2021, 2022). And if all these are not enough, or maybe, because of these, students, ranging from junior high (Baram-Tsabari & Yarden, 2005) up to undergraduate university level (Ornek et al., 2008), have an aversion to physics. It is our hypothesis that formal as well as informal physics teaching employing circus environment can meet these challenges. Thus, the present study provides a research foundation for experiential physics teaching through circus shows. Acknowledging the mentioned above ideas, herein we go further introducing the idea of group dialogic discussions to physics teaching anchored in circus art.

Dialogic discussions are known as an instrument to identify conceptual barriers (misconceptions) and facilitate their further revision thus, producing the desired conceptual change (Eshach, 2009). Indeed, instruction that includes the dialogic aspect is argued to engage students in meaningful learning processes (Scott & Ametller, 2007). In meaningful learning students' views are sought and valued as a part of the construction of scientific knowledge (Lehesvuori, 2013). These are the exact characteristics of a whole class dialogic discussions (WCDDs) (Eshach, 2009) as we further explain. Ponnambalam (2011) argues that "the facts/laws of physics may be cold to many; but the presentation of these laws can be very warm, lively, passionate–and even dramatic and poetic" (p. 393). Introducing physics concepts through *dialogic discussions about circus tricks* (DDCT) may definitely be such a "warm, lively, and passionate" way. We, moreover, believe that the strong motivation to understand circus tricks, engaged by circus performers (as it takes place in the present study) or, by physics instructors, has the power to lure people into a serious study of physics and contribute to changing its negative public image.

The present study actually originates in 2014 at a Dead Sea Hotel. One of the authors (Volfson A.) being also a circus artist, performed in the hotel during the summer season. One of his numbers included the following trick: the artist spins two open bowls connected by a rope and filled with water round and round, combining vertical and horizontal planes of rotation (**Figure 1**).

The water does not spill out. Once, following the compliment at the end of this number, the artist asked the audience: *What do you think, why did the water not spill out of the bowls?* What was the surprise when 15-20 children and adults out of about 50 spectators remained after the show for a 15 minutes' serious DDCT. This was despite the various competing enjoyable stimuli around such as concerts, dance pole, bar etc. We report the results of this experiment in our preliminary study (Volfson et al., 2022). Further, we developed the idea into an educational circus activity called "Between circus and science" including a full time circus show and a juggling master-class both based on DDCT dealing with ballistic motion, Newton laws, circular motion, rigid body mechanics, heat theory etc. as can be seen in the following promotion video clip: https://youtu.be/ZfdrPwePlil.

Figure 1. The artist spins the bowls in the horizontal plane (photo by Alex Vainberg & **the presenter is Dr. Alex Volfson, one of the authors of this article**) (left) & the artist conducts a dialogic discussion about the number (photo by Omer Armoni, Bazoola Productions) (Source: Authors' personal archive)

Following our preliminary study which examined the hetero-aged public understanding of circular motion physical principles as expressed in DDCT conducted during or after circus shows (we related them as focus-group interviews) (Volfson et al., 2022), the goals of this study are twofold:

1. Introducing DDCT as a diagnostic tool for identifying participants' conceptual understanding of Newtonian mechanics, rigid body mechanics and heat issues as well as, examining how participants utilize what they have learnt in physics classes to explain the physics principles of circus numbers and tricks.
2. Examining the conceptual change processes within a series of DDCT activities. That is, circus shows and master-classes, which include (and sometimes, based on) dialogic discussions between the artist and an audience about the underlying physics principles of the numbers and tricks performed by the artist. This might help us to: examine whether DDCT have the potential to engage a group of people from different age groups and backgrounds in physics; increase our understanding of what particular aspects in DDCT are useful in engaging people with physics ideas; and provide examples of DDCT for future use.

It should be emphasized that bringing circus to physics classes does not require, of course, that every physics teacher should be a professional circus artist. Physics teachers can expose their students to the world of circus by bringing some simple circus equipment to their classes, taking students to circus shows and further discussing what they have seen, or analyzing certain circus tricks presented in a video.

LITERATURE REVIEW

Understanding new physics concepts/developing misconceptions into correct scientific views requires conceptual change. According to the seminal work of Posner et al. (1982), conceptual change occurs when a learner's central commitments require modification. Here the learner is faced with a challenge to his basic assumptions. In this case, a student

> "… sometimes uses existing concepts to deal with new phenomena … Often, however, the students' current concepts are inadequate[2] to allow him to grasp some new phenomenon successfully. Then the student must replace or reorganize his central concepts. This more radical form of conceptual change we call *accommodation"* (p. 212).

Physics teaching is known to frequently be an arena for educators' dealing with physics misconceptions, frequently robust (see, for instance, Chi et al., 2012; Demirci, 2005; Ding et al., 2013; Eshach & Schwartz, 2006; Hestenes et al., 1992; Roche, 2001; Volfson et al., 2018, 2019, 2022; Vosniadou, 2013; Vyas, 2012). Thus, looking for new ways aimed at identifying misconceptions as well as facilitating conceptual change is of both, theoretical and practical interest in physics teaching. In what follows we first summarize the literature on

[2] Similarly to other contemporary works in field of conceptual change, we call these "inadequate" concepts misconceptions.

dialogic discussions, we then go on to discuss the possible contribution of circus environment to physics education and finally, we show the potential of DDCT to facilitate conceptual change about physics concepts.

Dialogic Discussions

Science education has been mainly limited to the study of *solo cognitive*, rather than *socio-cognitive*, processes (Hogan, 1999). This means that the focus of the studies was on the individual's conceptual change process rather than on conceptual construction occurring within groups of learners. The study presented here joins the line of research that focuses on understanding how knowledge is constructed in teacher-led discussions, which has not yet been sufficiently addressed (Eshach, 2009; Eshach et al., 2017; Lehesvuori, 2013). The "class" in this research is actually the audience of a circus show, and the teacher is the artist.

Scott et al. (2006) distinguish between authoritative and dialogic discourse. While in "authoritative discourse the teacher's purpose is to focus the students' full attention on just one meaning … in dialogic discourse the teacher recognizes and attempts to take into account a range of students', and others' ideas" (Scott et al., 2006, p. 610). WCDD is rooted in the premise of social constructivism (Cobb, 1994; Ernest, 1993). Going back to the seminal work of Vygotsky (1978), this view gives substantial weight to the role of social interactions in learning and sees knowledge as primarily a cultural product. Indeed, the learning of the individual, according to Vygotsky (1978), is preceded and accompanied by inter-individual functioning: higher psychic functions appear in interpersonal interaction before becoming intrapsychic. Dialogic discussions enable students, with the help of instructors' prompts, to reveal their own ideas, confront those ideas with other ideas, adopt or reject other ideas, create hybrid ideas, and sharpen their ideas (Eshach, 2009; Lehesvuori, 2013). This is crucially important for detection and identification of misconceptions (Volfson, 2013, 2018; Volfson et al., 2020a, 2020b; Vosniadou et al., 2001; Wells & Arauz, 2006) and may lead the learner to the desired conceptual change (Eshach, 2009).

Dialogic discussions are characterized by an IRPE structure (Eshach, 2009). In this structure, "I" stands for initiation–usually a question from a teacher or an artist (as we show below), and R is a participant's response to that initiation. P is a prompt, which refers to feedback from the teacher (artist) to the participants' responses, in order to prompt further elaboration of their points of view. Finally, E stands either for the evaluation of the answers, or in other situations it may function to "extend the student's answer, to draw out its significance, or to make connections with other parts of the students' total experience during the unit" (Wells, 1999, p. 200). All these are also relevant to DDCT.

Structures of Conceptual Flow Patterns

Teacher's (artist's) interventions influence student (audience) discourse while, on the other hand, especially in dialogic discourse, the various student (spectator) responses affect teacher's (artist's) interventions. All these coalesce as *conceptual flow patterns* (Eshach, 2009). conceptual flow patterns treat the growth, transitions, and sometimes extinction of concepts as they arise during classroom discussions of a certain topic. Eshach (2009) analyzed the conceptual flow patterns of dialogic discussions using diagrams, which he called *conceptual flow discourse maps* (CFDM). He identified the following three patterns:

(a) *Accumulation around budding foci concepts:* A student introduces a new idea into the classroom discussion and this idea becomes the focus of the whole-class discussion. The idea is discussed for a while until another idea buds and the discussion changes its focus to the new idea.

(b) *Zigzag between foci concepts:* Some main ideas are adopted by different student groups. The discussion *zigzags* between those groups[3].

(c) *Concept tower:* Previous concepts and learning experiences are synthesized into the construction of more complex scientific ideas (**Figure 2**).

Physics Education Potential of DDCT

Circus environment is full of tricks, props and devices, which all are based on simple physics principles. In the present study we shall relate ballistics, Newtonian mechanics (inertia, force, energy, circular motion, etc.),

[3] Eshach (2009) observed and analyzed *zigzag* between two foci concepts. While we bring in the present study discourses *zigzag*ging between three and four foci concepts.

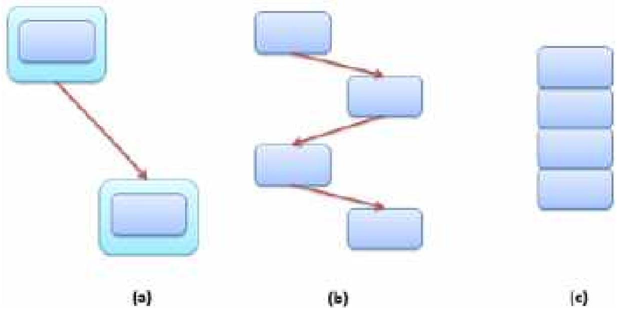

Figure 2. The three CFDM structures: (a) accumulation around budding foci concepts, (b) *zigzag* between foci concepts, & (c) concept tower (Eshach, 2009)

Figure 3. Balls fly in parabolic trajectories (photo by Marina Aletko & **the presenter is Dr. Alex Volfson, one of the authors of this article**) (Source: Authors' personal archive)

rigid-body mechanics and classic heat theory as we further demonstrate. By using the term 'simple' we mean that the background knowledge needed for explaining these tricks, props and devices is only knowledge on the mentioned above issues and no further knowledge such as electricity, electronics, chemistry etc. is needed. This approach of teaching physics via the analysis of real situations and devices meets the requirements of contemporary science teaching standards (International Technology Education Association [ITEA], 2007; NGSS, 2017) and is based on the understanding that it is not enough to learn about abstract science concepts and rules in order to apply them to a variety of situations we encounter in everyday life, but this practical application must be taught explicitly (see, for instance, Eshach, 2009). Findings of our previous works (Volfson et al., 2018, 2020a) certainly reinforce this idea.

All the tricks and numbers are demonstrated in the real time to the audience. Most of them can further be re-demonstrated and/or modified serving the aims of the artist (teacher) providing DDCT. Circus arts master-classes (acrobatics, juggling, and fire spinning) relate in addition the embodied knowledge of the participants thus providing another facility for learning the physics principles. Indeed, embodied knowledge (embodied cognition) is not simply knowledge of the body, but knowledge dwelling in the body and enacted through the body (Craig et al., 2018). The cognitive systems of learners are affected, even constrained, by action and perception (Weisberg & Newcombe, 2017). Let us now demonstrate these in the following three examples.

Example 1: Juggling–ballistic motion and center of mass

Once thrown, all the props (balls, rings, and clubs) fly in parabolic trajectories (**Figure 3**). Due to the gravity force they are found most of the time at the top part of the trajectory. These two facts enable the juggler to predict the motion of the prop looking at the upper part of the trajectory, lend his hand and catch it. Another phenomenon which can be felt when experiencing juggling is that the time of the prop on its way up is equal to its time on the way down.

Figure 4. The club performs a parabolic trajectory in the air and spins around its center of mass found near its "head" (photo by Omer Armoni, Bazoola Productions & **the presenter is Dr. Alex Volfson, one of the authors of this article**) (Source: Authors' personal archive)

Figure 5. A tight grouping in a somersault (photo by Marina Aletko & **the presenter is Dr. Alex Volfson, one of the authors of this article**) (Source: Authors' personal archive)

Energy conservation law can also be demonstrated and experienced through juggling. The teacher (artist), for instance, can emphasize the experience of kinetic energy (near the hand) conversion to potential energy (on the top) and vice versa. Further, the initial velocity *v* of throwing can be easily calculated by estimating the maximum height *h* of the prop and further applying the mechanical energy conservation law:

$$\frac{1}{2}mv^2 = mgh => v = \sqrt{2gh}.$$

This example, no doubt, is almost trivial. We believe there is no introductory physics textbook which does not relate it in some way. Circus show setup, however, enables visual and experiential demonstration, while juggling master-class enables also to relate the embodied knowledge. Such "through body" experience can be an aid in in understanding the quite abstract and often misconceived concept of energy (Ding et al., 2013).

Further developing of juggling skills with less symmetric props, such as clubs (**Figure 4**), one explicitly sees how every flying object once rotated, spins around its center of mass. While every club performs a parabolic trajectory in the air, it has to be rotated in a certain angular velocity in order to be caught properly by the juggler. The club always spins around its center of mass found near its "head" which enables the juggler to catch it by the handle.

Example 2: Moment of inertia in acrobatics and spinning props

One of the central movements in a somersault[4] and a salto[5] is the grouping–bending the knees and keeping them by catching the shins by hands; thus, turning the body of the acrobat into a "ball" (**Figure 5**). The moment of inertia of a ball is $I_{ball} = \frac{2}{5}mR^2$, where *m* is the mass of the ball and *R* is the radius (see, for instance, Ewen & Heaton, 1981).

[4] Also called *culbit*–A dynamic or individual element with rotation with hands support to the back and legs.

[5] An acrobatic element in which a person's body rotates 360^0 or more around a horizontal axis with no hand support during the rotation.

Figure 6. Center of mass and moment of inertia of a staff (photo by Marina Aletko & **the presenter is Dr. Alex Volfson, one of the authors of this article**) (left) & Flower-stick is much shorter and lighter than a staff and thus, has much smaller moment of inertia (photo by Omer Armoni, Bazoola Productions)

Figure 7. The artist jumps into burning rings (photo by Omer Armoni, Bazoola Productions & **the presenter is Dr. Alex Volfson, one of the authors of this article**) (Source: Authors' personal archive)

Therefore, the angular velocity of a rolling ball is $\omega = \sqrt{\frac{5E}{m}} \times \frac{1}{R}$ when *E* is the rotational kinetic energy which the acrobat got at the start of the somersault (we look at the acrobat as a spherical body in the first approximation and neglect friction). This teaches us that the tighter the grouping, the smaller is the radius of the "ball" and thus, the greater is the angular velocity. That is, the acrobat rotates faster (Volfson, 2013). This point can be well observed in different acrobatic jumps involving tight grouping and, on the contrary, salto with a straight or bent body. It is also well experienced while studying a somersault at almost the first acrobatics lesson or a master-class.

Moment of inertia can be considered as the body's resistance to changes of the angular velocity vector (Savel'ev, 1998) and thus, can be also well experienced in spinning various props. Let us look, for instance at a staff. It constitutes an about *L=1.2 m* wooden rod of mass *m* with rubber bobs (flowers) each of mass *M* at its ends (left part of **Figure 6**). When spinning staff around its center of mass, its moment of inertia is $I_{staff} = \frac{1}{12}mL^2 + M\left(\frac{1}{2}L\right)^2 + M\left(\frac{1}{2}L\right)^2 = \frac{m+6M}{12}L^2$, where the first term is the moment of inertia of the rod, the second one is the moment of inertia of the left weight, and the third one is the moment of inertia of the right weight. That is, the longer is the rod and the bigger are the masses; the whole moment of inertia is higher. This is the reason that a staff resists immediate changes of its rotation plane and spinning velocity. The change of rotation plane should be gradual, via "eights" for instance. While a smaller and easier flower-stick (right part of **Figure 6**) has much smaller moment of inertia. This fact can be well experienced while comparing the staff and flower stick dynamics while spinning.

Example 3–Fire, heat capacity, and heat transfer

Fire shows (**Figure 7**) provide the stage to demonstrate and discuss the principles of classical heat theory. Indeed, questions like: What is heat? How does heat propagate in the air, from the flame to our body? Why does heat is better felt above the flame? What keeps the fire artist from getting burned while the show? These questions deal with the nature of heat, heat transfer, convection and heat capacity; and thus, are of a potential to be fruitful for explaining these concepts and for treating materialistic misconceptions of heat (Chi et al., 2012; Volfson et al., 2019).

DDCT and Conceptual Change

Constructivist educator, who attempts to move students towards a conceptual and qualitative understanding of physics ideas needs, at the first stage, to be informed about how students see the physical world and take their points of view into consideration when designing instruction (Eshach, 2009; Galili & Hazan, 2000; Hestenes et al., 1992; Hrepic et al., 2010; Treagust, 2006; Vosniadou et al., 2001). One way to identify students' knowledge about scientific concepts is the use of focus-group interviews *(*Dilshad & Latif, 2013; Volfson et al., 2020a) or non-authoritative WCDDs oriented at investigating of students' thinking (Eshach, 2009; Volfson et al., 2022) which in a sense are similar. Group members in such discussions should feel relaxed and comfortable and enjoy sharing their ideas and perceptions (Dilshad & Latif, 2013; Krueger, 1988). The fact that a large portion of those who came just to watch a circus show in the hotel, remained and actively participated in the after-show DDCT, demonstrates that circus indeed offers a unique non-formal environment for providing comfortable and interesting discussions as the literature requires (Krueger & Casey; 2000; Rabee, 2004) thus promising a better cooperation of participants.

At the second stage, the educator has to produce the conceptual change towards the correct understanding. According to the classical model of Posner et al. (1982) conceptual change can occur by the creation of cognitive conflict through the presentation of anomalies (Rowlands & Graham, 2005). That is, the educator has to engage dissatisfaction with existing conceptions among the learners as unable to explain the demonstrated/discussed phenomena. Once learners have collected a store of unsolved puzzles or anomalies and lost faith in the capacity of their current concepts to solve these problems, the educator has to come up with the scientifically correct conception. This novel conception needs to be intelligible, plausible and able to predict and explain further alike phenomena.

According to Rowlands et al. (2007) such an attempt has to "… *involve a meta discourse component that encourages students to reflect on their misconceptions and the coherence of their physics knowledge systems.*" (p. 36). All these are actually come to fruition in WCDDs as outlined by Eshach (2009). DDCT we suggest in the present study are in a sense a direct extension Eshach's (2009) discussions conducted in the informal circus environment.

Research Aims and Questions

The present study aims at examining the potential of DDCT as a diagnostic tool for identifying participants' conceptual understanding of Newtonian mechanics, rigid body mechanics and heat issues as well as, examining how participants utilize what they have learnt in physics classes to explain the physics principles of circus numbers and tricks; and examining whether and how theoretical concepts in these fields can be learnt through DDCT provided in circus shows and master-classes. Thus, the following research questions will guide our study:

1. Whether and how DDCT can be used to reveal and identify physics misconceptions?
2. Whether and how DDCT can facilitate conceptual change regarding physics concepts?

METHODOLOGY

Study Population

As it was already said, the present research actually began in 2014. Seven shows containing DDCT about circular motion (Volfson et al., 2022) were performed by the KESHET circus artists in the hotel on the Dead Sea in Israel. About 50 spectators of various ages watched each show. Of these, 10 to 20 people remained after each show and participated in a discussion (about 105 people in total). Since the 2014 preliminary research (Volfson et al., 2022) we developed the DDCT repertoire to other fields of physics as well as appropriate shows and master-classes especially basing on DDCT. About 30 such shows and master-classes were provided since then. In total, about 5500 people watched the shows. From them, about 400 actively participated in the DDCT. Most of these discussions were video recorded and transcribed verbatim; others were written down while observations or, immediately after the shows.

The Circus Act

In our approach every circus act/number/trick provides an initiation for a DDCT. Following the number, the artist first asks the audience to explain the physics of the trick and further challenges the participants' views with some modifications of the trick, other tricks or other props. For instance, in the preliminary research (**Figure 1**), the artist asked the audience:

(a) why the water did not spill out of the bowls; and

(b) predict what would have happened to the bowls if the rope were to tear during their motion at some specific point (in horizontal plane, when one of the bowls is in front of the artist, and in the vertical plane when the bowl is on the top).

At the beginning of the discussion the artist asked the participants to express their views regarding the presented phenomenon, to refer to each other's explanations, and relate to challenging questions. The artist not only provided verbal prompts, but rather used demonstrations to further challenge the participants' view in cases he felt were needed. Once the participants expressed their ideas, the artist summarized the discussion and explained, in a qualitative manner, the underlying physics of the circus number. He began with explanation about Newton's first law and then explained that at every point of the path, each bowl 'strives' to continue moving in a straight line in a tangent to the path direction, but since the rope holds it, it is forced to move in a circular path, due to the action of centripetal force (tension of the rope in this case). The water in the bowl also strives to continue moving in the tangent direction, however, it is blocked by the bowl, which exerts a force on the water. This makes the water stay in the bowl. The artist also emphasized that there is no centrifugal force, but on the contrary, there is a force which pulls the bowls to the center of the circular motion path–the centripetal force, tension in this case. The artist explained all these in laymen's terms, without using any formula (Volfson et al., 2022).

In eight of the DDCT in the preliminary research the artist announced that the correct answers would be awarded by a prize. At three shows the artist rewarded by prizes every novel and scientifically considerable answer–that is, not necessarily the correct one, but every answer that suggests a "theory" explaining all the provided demonstrations and developing or rejecting previous explanations of the other participants. And at the other three shows the artist did not offer any reward at all. The reward turned the discussions into a kind of a game or quiz and thus, facilitated the cooperation of participants and contributed to the atmosphere of entertainment. The fact that no difference, neither in the suggested explanations, nor in their variety or frequency was observed in these shows, teaches us that the answers obtained in the research reflect true misconceptions (i.e. really deep-seated ideas about how the physics works) and not some "making up" answers excogitated just to participate and get a prize.

Data Analysis

In order to trace and examine the conceptual flows in the DDCT, as well as identifying participants' views of the physics phenomena, an inductive analysis was performed on the transcriptions by the authors (a professor of science education with 15 years of experience and two PhD physics lecturers) according to Eshach and Schwartz (2006), Fridell and Ekberg (2016), and Patton (1990). The analysis process actually, went through the following six steps according to Eshach and Schwartz (2006) as well as Fridell and Ekberg (2016):

a. First reading of the transcribed data to obtain a comprehensive overview (Roth, 1995).

b. Subsequent readings by each researcher individually searching for certain themes or patterns (of misconceptions as well as correct explanations) across an (entire) dataset (Braun & Clarke, 2006) forming the categories.

c. Re-reading the data by the two authors together to confirm the categorization process.

d. Association of the various items of meaningful content found in the texts with the relevant categories-coding. The coding process was done along the lines of that used by Slotta et al. (1995) as well as Eshach and Schwartz (2006). It consisted of identifying keywords or sentences that reflected one of the views discussed in the next section. For instance, a sentence like "a force pushes the water out and you blocked the water!" reflects the *centrifugal force* misconception.

e. Review of the categorization to ensure that it reflects the relevant concepts. Certain ideas were re-categorized at this stage.

Next, CFDMs were created for each DDCT, as specified by Eshach (2009). A new idea which was expressed during the discussion as well as the interventions, which related to the same idea, were grouped and visually placed in a box. When a move was made to a new idea, which was not expressed previously, it, as well as the interventions that related to this view, were again put in another Box. This second box was placed lower down to represent the order in time by which the ideas were presented. Interventions which were not relevant, such as technical ones, were omitted from the CFDM, which focused on the visual presentation of the flow of views during the DDCT. We bring four representative examples for such DDCT analysis in the next section.

RESULTS

This section represents four typical DDCT provided in circus shows as well as during master-classes. Each DDCT is analyzed in the spirit of Eshach (2009) using appropriate CFDM following a short qualitative analysis of participants' ideas that came up in each discussion. The DDCT deal with the following concepts:

(a) circular motion,

(b) moment of inertia,

(c) torque, and

(d) heat transfer.

DDCT 1–Circular Motion

Here is a typical example of a discussion that took place while a show in front of about 100 spectators. It lasted about 15 minutes. The CFDM (**Figure 3**) represents the answers of eight participants (adults and adolescents). It has two parts, each related to one of the questions: part a-why did the water not spill out; and part b-if the rope holding the bowl suddenly tears, at what trajectory will the bowl fly. The structure of the conceptual flow pattern is *a zigzag* (**Figure 8**) as there is a transition between the following three mistaken views (one can find a detailed analysis of these views in our previous work, Volfson et al., 2022):

a. *Centrifugal force:* According to this view, when we spin an object, an actual centrifugal force appears and pushes the object outside of the path, in a radial direction (as specified by Demirci, 2005; Hestenes et al., 1992; Vyas, 2012).

b. *Speed of spin:* Those who expressed this view referred primarily to the case of spinning the bowls in a vertical plane, although in the show the artist rotated the bowls both vertically and horizontally. According to this view, the artist spins the bowls so fast that the water actually does not have enough time to spill out when the bowls are overturned on the top of their path.

c. *Air pressure:* Pressure resulting from fast motion of the water relative to the air–according to this view, when we spin the bowls quickly enough the air exerts an increased pressure on the water. This pressure keeps the water inside the bowls.

After performing the number of spinning two bowls full of water, the artist put the bowls down, and asked the audience to:

(a) Explain why the water did not spill out of the bowls; and

(b) Predict what would have happened to the bowls if the rope were to tear during their motion at some specific point (in horizontal plane, when one of the bowls is in front of the artist, and in the vertical plane when the bowl is on the top).

The first idea, expressed by three participants, was the existence of the so called *centrifugal force*. It seems that they view the action of a centrifugal force on bodies moving in a circular path as a fact, without understanding its nature: "*It's a centrifugal force. When you spin something, it's pushed outside*", explained participant 2. The discussion then went to the idea of *air pressure* resulting from the fast motion of the bowls relative to the air. As participant 4 explained and showed by gestures, an increased amount of air enters the bowls and presses the water. While this new idea was expressed, the previous idea remained within the group. Participants 5 and 6 than combined the new idea of air pressure with the centrifugal force one and

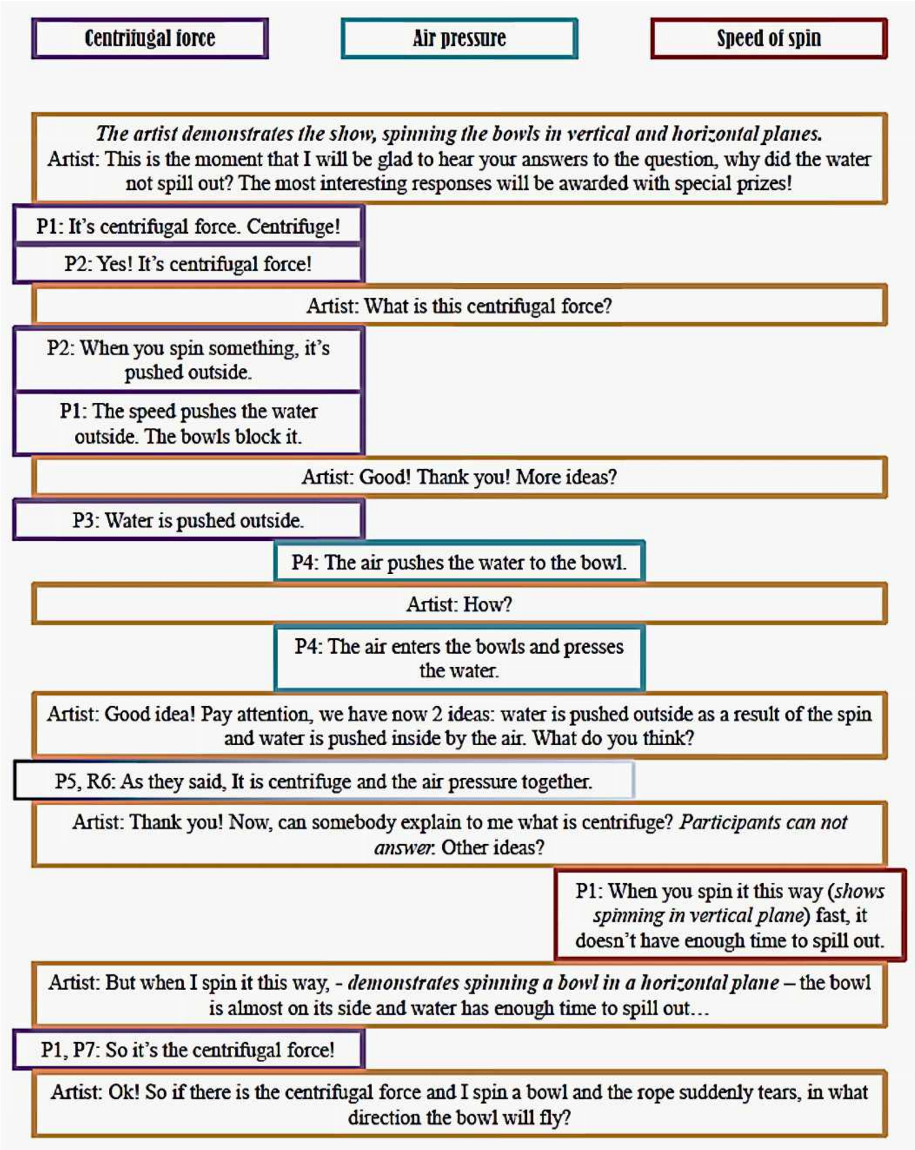

Figure 8. CFDM of a typical DDCT on why water did not spill out. Discourse structure is a *zigzag* between three foci concepts (Source: Authors' own elaboration)

created the hybrid idea (term taken from Vosniadou, 2013), according to which, both the centrifugal force and the air pressure are responsible for keeping the water in the bowls.

At this point, to challenge the participants' views regarding the centrifugal force, the artist asked them to explain "what is centrifuge (term used by participant 1)?" Participant 1, who was the first to express the *centrifugal force* idea, offered another explanation: that rotation in the vertical plane (as he showed with gestures) is so fast that the water does not have enough time to spill out (*the speed of spin idea)*. The artist challenged this idea by asking if this is the case in horizontal spinning, after all in such a case, he added, the water "has enough time to spill out" but, as the provided demonstration shows, this does not happen. This remark led participants 1 and 7 to express the idea that the centrifugal force is probably the only responsible reason for the water to stay in the bowls.

As a result of this process the participants expressed as a possible reason for the water not being split out of the bowls the *centrifugal force*. The artist then went on to challenge this view by asking the question about the tearing rope. **Figure 9** is the CFDM of the discussion concerning this question. The idea behind this question was that if students believe that there is a centrifugal force, they will probably think that releasing the rope will result in a movement of the bowls *outside in a radial direction* or *in a diagonal* one. In such a case a demonstration of spinning and releasing a bowl would challenge the *centrifugal force* concept.

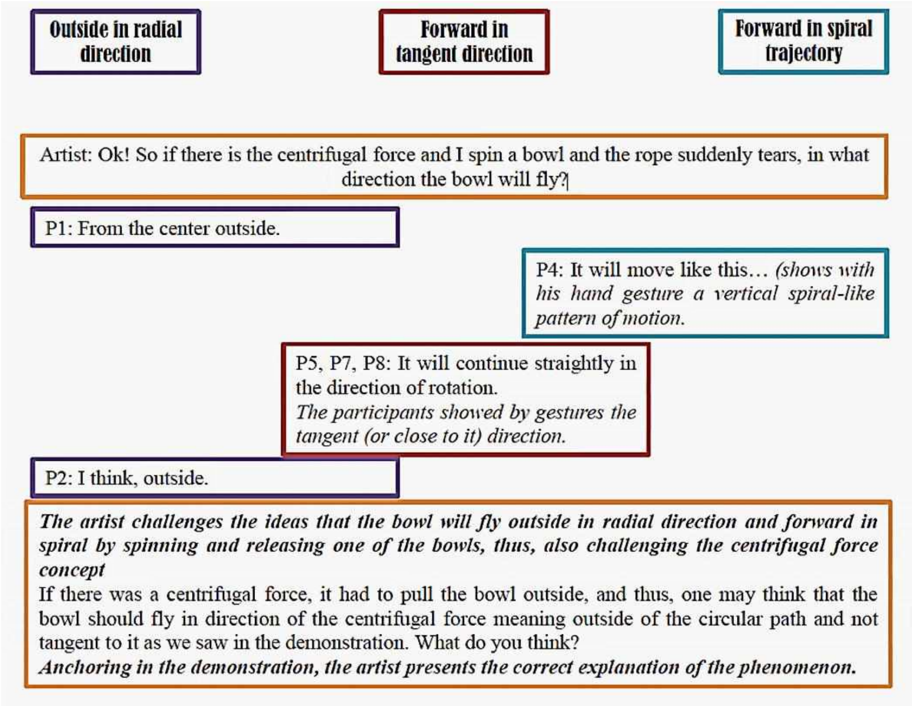

Figure 9. Typical DDCT about the possible direction of a bowl if the rope tears. The structure is also a *zigzag* between other three foci concepts (Source: Authors' own elaboration)

Participant 4 argued that the bowl would continue to move in a spiral path, this in accordance with the *circular impetus* view (Hestenes et al., 1992). Participants 5, 7, and 8 contended that the bowl would continue "*straight in the direction of rotation*" (the correct answer). Participants 1 and 2, who had previously expressed the idea of *centrifugal force,* indeed claimed that the bowl would fly from the center outside.

The artist challenged the ideas that the bowl will fly *outside in radial direction* and *forward in a spiral* by spinning and releasing one of the bowls, thus also challenging the centrifugal force concept. He addressed the audience and said: "*if there was a centrifugal force, it had to pull the bowl outside, and thus, one may think that the bowl should fly in the direction of the centrifugal force meaning outside of the circular path and not tangent to it as we saw in the demonstration. What do you think?*" Anchoring in the demonstration, the artist presented the correct explanation of the phenomenon.

DDCT 2–Moment of Inertia

This DDCT took place at a juggling master-class conducted in a group of about 15 engineering students (first and second years). The master-class was conducted by two artists and provided a part of entertaining activities in a desert hotel. The artists opened the class with presentation of three objects' juggling. One of the artists then explained while juggling three rings, that when one throws up a juggling ring, he has also to spin it with his palm. This spin is needed to stabilize the ring's trajectory in the air since every rotating body maintains its spinning axes. "*This is called moment of inertia,*" the artist emphasized and challenged the auditory: "*What is this moment of inertia? Why does it exist?*"

Two students argued that there is a force which resists changes of the rotation plane and axis. This statement seems to be similar to the idea of *circular impetus* or, circular inertia making a spinning object to continue rotating in the circular trajectory. Due to this idea, body leaving a circular path for some reason will continue to spin in an expanding spiral (Hestenes et al., 1992). Moreover, it seems that such *circular impetus* was considered by these students like a real force ruling a spinning ring motion similarly to linear impetus which was also mistakenly considered as a real force in the pre-Newtonian mechanics (Samovarski, 1987). Third student objected this idea and suggested that this is actually the *centrifugal force* which stabilizes the ring. Indeed, centrifugal force is expected to pull every element of mass of the ring outside in the radial direction. Since, all the mass elements are pulled outside in the plane of spinning; centrifugal force is logically expected to be the reason for maintaining the plane (axis) of rotation.

Figure 10. Presentation of a spinning plate. The plate is stable on the rotation axis (Source: Authors' personal archive)

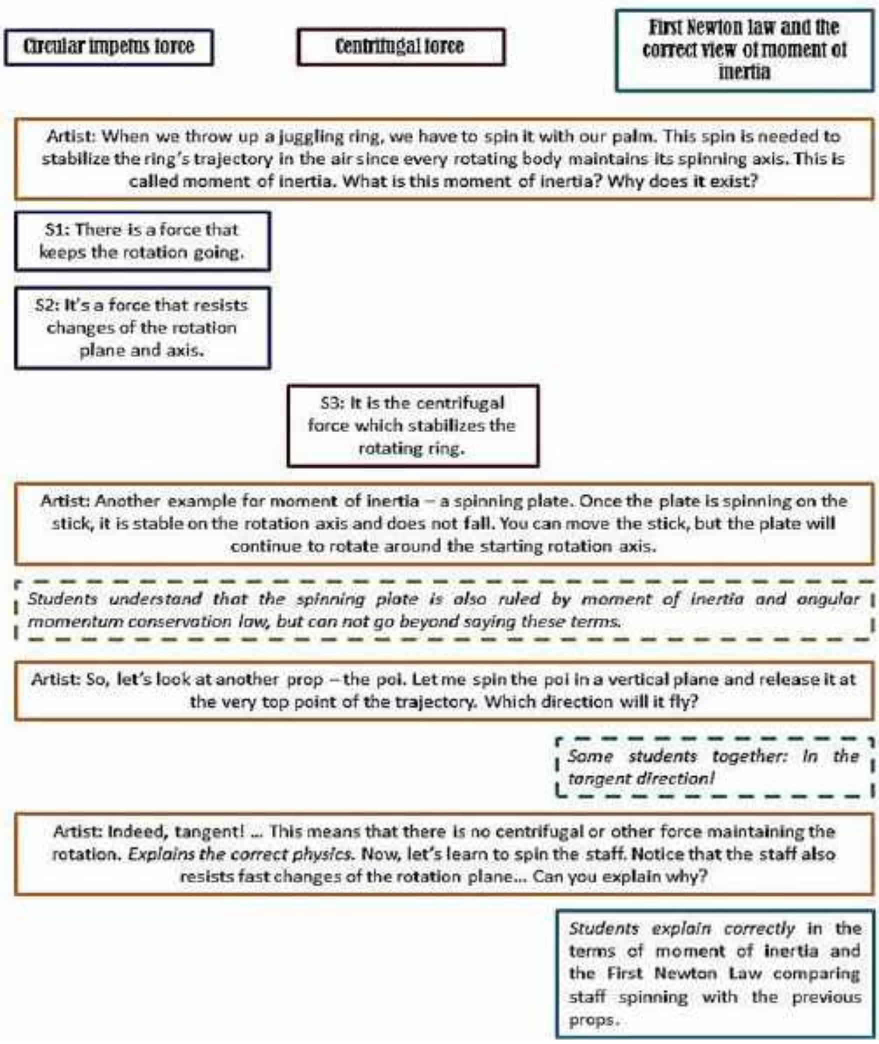

Figure 11. DDCT about the concept *moment of inertia* provided on a juggling master-class (Source: Authors' own elaboration)

To develop the moment of inertia theme, the artist presented another prop–the spinning plate (**Figure 10**). He rotated the plate and emphasized that once the plate is spinning on the stick, it is stable on the rotation axis and does not fall. "*You can move the stick, but the plate will continue to rotate around the starting rotation axis*" the artist demonstrated. The students considered that the new situation also involves moment of inertia and angular momentum conservation but could not go further and explain the nature of these terms. As one of the students said, "W*ell, we did not study these concepts so in depth*" (**Figure 11**).

Figure 12. Game with the trident. The trident rolls down (photo by Marina Aletko) (Source: Authors' personal archive)

To challenge both ideas *force of circular impetus* and *centrifugal force*, the artist demonstrated the third prop–a pair of poi. The artists first performed a short number of poi's spinning. Following the number, the artist asked the audience: "*Let me spin the poi in a vertical plane and release it at the very top point of the trajectory. Which direction will it fly?*" Almost all the students answered immediately: "*in the tangent direction!*" as they probably had learned in physics courses. The artist demonstrated this point and exclaimed: "*Indeed, tangent! But why? If there is a centrifugal force, it has to bounce the poi up. And if there is a force that maintains rotation, the poi should have continued the circle or spiral trajectory. Both do not happen! This means that there is no centrifugal or other force maintaining the rotation.*"

Here the artist explained, in a qualitative manner, the underlying physics of moment of inertia. He began with explanation about Newton's first law and then explained that at every point of the circular path, each mass element 'strives' to continue moving in a straight line in a tangent to the path direction, but since the rope (in a poi) or the material stiffness (rings and plates) holds it, the mass element is forced to move in a circular path, due to the action of centripetal force (tension of the rope, stiffness of the material). Since the velocity vector is always tangent to the circular trajectory and thus, parallel to the rotation plane, every element of mass 'strive' to continue moving in this plane due to the inertia principle–the first Newton law.

To examine students' understanding, the artist presented the staff–a wooden rod about *1.2 m* long equipped with relatively heavy rubber bobs on its edges. He showed how to spin the staff and emphasized that the staff also resists immediate changes of rotation plane. Thus, the change of rotation plane should be gradual, via "eights" for instance. He asked to clarify this fact. The students succeeded to explain it in the correct terms of moment of inertia and the first Newton law as the artist taught relatively the previous props.

DDCT 3–Torque on the Trident

Another number the artist performs is the game with the trident. While the number, the artist rolls the trident on his arms and body. The basic roll of the trident is down an arm as **Figure 12** demonstrates. The following discussion took place on the Between circus and science show provided in front of about 70 high school physics students (10-12 grades). Following the number, the artist asked: *Why does the trident rolls down my arm? What is the physics of this process?* Next to students' answers, the artist summarized the discussion and neatly explained that there are actually two opposite forces acting on the trident: $mg\sin\alpha$ component down the hand and static friction f_s acting against the direction of motion, that is, up the hand, as **Figure 13**. Since these forces act on two different points of the trident–center of mass found on the central axis of symmetry and the shaft surface, they result in a torque–the tendency to cause rotational motion (Ewen & Heaton, 1981). Thus, the trident rolls down the arm.

Obviously, since the students have been already familiar with the mechanics of a body sliding downs an inclined plane (when the $mg\sin\alpha$ component acts down along the plane), the problem of the rolling trident

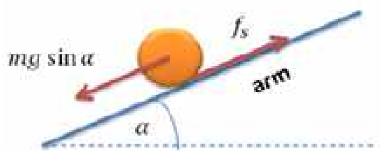

Figure 13. Trident rolls down the hand since there are two opposite forces: $mg\sin\alpha$ acting on the center of mass and static friction f_s acting on its surface (Source: Authors' own elaboration)

Artist: Why does the trident rolls down my arm? What is the physics of this process?

S1: Gravity pulls the trident down.

Artist: But if it is only gravity that pulls the trident down, it should only slide down. So, why does it roll?

S2: Friction causes it to roll.

Artist: How? Friction usually restrains motion…

S3: Gravity acts on the center of mass. Friction acts on the shaft surface. This makes the trident to roll.

Artist: Correct! *Summarizes the discussion and explains once more time.*
Bounces the trident.
Now let us look at another trick! Why does the trident rotates when I bounce it this way? Why doesn't it "jumps" up flatly?

S4: One side is pulled down by the gravity. The other one is bounced up by your hand. There is a torque!

S5: It's again the situation, as you explained, when two opposite forces act in different points creating a torque

Artist: Great! You are right! *Summarizes the discussion and explains once more time.*

Figure 14. DDCT about the rolling and rotation of the trident–concept tower (Source: Authors' own elaboration)

was found in their ZPD[6] and thus, the discourse is characterized by the concept tower structure according to Eshach's (2009) classification as **Figure 14** shows.

Indeed, Eshach (2009) notes that concept tower structure is "… prone to appear toward the end of a certain learning phase and usually at the end of the learning sequence" (p. 16); that is, when the students have a thorough base of material enabling them to deal with the under consideration problem. As can be seen in **Figure 14**, there was no *zigzag* between different views, but on the contrary, each participant added, in his turn, next part of explanation thus constructing the correct understanding of the phenomenon.

Next, in order to challenge the students as well as to examine their understanding, the artist bounced the trident slightly hitting it at a certain distance from its center of mass. As a result, the trident rotated in the air. The artist then asked the audience: *Why does the trident rotates when I bounce it this way? Why doesn't it "jumps" up flatly?* Some students explained correctly that *mg* pulls the center of mass down while the artist's hand applies a force up at a point slightly away of the center of mass. *It's again the situation, as you explained, when two opposite forces act in different points creating a torque!*–said one of the students.

DDCT 4–Heat Transfer

This DDCT took place at a physics Olympiad for high school students. About 120 high school physics students and 20 teachers watched the show. The artist performed the fire show number. The number

[6] ZPD–Zone of proximal development. ZPD according to Vygotsky (1978) is "*the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem-solving under adult guidance, or in collaboration with more capable peers*" (p. 86).

included acrobatic jumps into burning rings (see **Figure 7**). After performing the number, the artist inspired the DDCT by asking the audience: "*Fire is hot. When I place my hand near a torch, I fill hot. What is heat? How does heat propagate from the fire to my hand?*" Surprisingly, the students eschewed answering these questions. However, two science teachers volunteered to explain the phenomenon. Since, the discussion was relatively short, let us bring it here in full.

> Teacher 1: Heat increases the molecules' velocity.
>
> Artist: So, the "hot" molecules flow faster from the torch to my hand?
>
> Student 1: No. The hot molecules go up. I don't remember how it is called …
>
> Artist: It is called convection. We shall get back to it further. But I also feel hot when I hold my hand aside the torch and not above it. Why is it?
>
> Teacher 2: Heat is the self-motion of the molecules. This motion increases as the material is hotter. For instance, air molecules move faster as a result of heating by the torch…
>
> Artist: Great! So, do these "hot" air molecules flow from the torch and hit my hand? That is, if molecule A is "warmed up" near the torch, what happens next?
>
> Teacher 2: The motion is random in all directions. So, it is probable that certain molecule will flow in the direction of your hand. Further, if your hand is found within the mean free path of the molecule, it would hit your hand.
>
> Artist: Thank you! Unfortunately, the mean free path of the air molecule is very-very small[7]. Therefore, the probability that certain molecule accelerated near the torch will hit the hand actually strives to zero. What happens here is that molecules which are close to the torch start moving faster and collide with their neighboring molecules. These molecules also hit their neighbors, and so on. What is true is that molecular movements and collisions indeed occur in all directions with the same probability. This is why I can place my hand at every point around the torch and feel the heat. This is called heat conduction.

Further the artist also explained in lame terms about convection and radiation.

DISCUSSION AND IMPLICATIONS FOR EDUCATION

The present study shows how the worlds of physics education and circus art can meet and contribute each other. Indeed, as the results of the study show DDCT seems to be an original and promising approach to bring advanced physics ideas to the general public, in ways that are interesting, experiential and relatively easy to understand for those without a physics background. Indeed, the artist conducted seven DDCT in a hotel, which was full of various competing enjoyable stimuli such as concerts, dance pole, bar, etc. Nevertheless, a relatively large portion of audience stayed after the shows to participate in the discussions.

Actually, circus art (these words should definitely begin with capital letters) turned the discussions into a kind of a game or a competition and thus, facilitated the cooperation of participants and contributed to the competitive but not judgmental atmosphere of entertainment which encouraged the participants to think about physics, analyze what they have just seen, express their ideas further comparing them with the reality (*if there was the centrifugal force, why does the bowl flies in tangent?*). This way, DDCT also teach the participants that, like in science itself, it is important to think and dare to make hypotheses, even though sometimes a hypothesis may be wrong. Consequently, DDCT can contribute both research and instruction aspects of science education as we next explain. In what follows we first discuss the potential of DDCT to reveal and identify physics misconceptions; second, we analyze how DDCT can facilitate conceptual change regarding physics concepts.

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[7] Actually, the mean free path for oxygen molecules at about 30 ^{o}C and *1 atm* pressure is 1.1×10^{-7} *m* (Halliday et al., 2014).

Research Aspect

There is general agreement today among physics educators that teachers' deep understanding of their students' knowledge is a necessary key step that might significantly help them in their efforts to design effective learning environments (Eshach, 2009; Galili & Hazan, 2000; Hestenes et al., 1992; Hrepic et al., 2010; Treagust, 2006). This view is expressed well by Vosniadou et al. (2001) who write that "*teachers need to be informed about how students see the physical world and learn to take their points of view into consideration when they design instruction*" (p. 392). We further agree with the contemporary science teaching standards arguing that simply learning "pure" physics concepts is not enough by itself. Students should also be able to apply these concepts in the analysis of real-life phenomena (ITEA, 2007; NGSS Lead States, 2017). This idea is well expressed by the Superintendent of Public Instruction (2018) requiring that students should "… build knowledge by actively exploring real-world issues and problems, developing ideas and theories and pursuing answers and solutions" (p. 65). However, one cannot assume a kind of "automatic" transfer of theoretical physics knowledge to its practical application (Eshach & Schwartz, 2006; Volfson et al., 2018, 2022). According to this line of thought, one cannot get a full picture of students' understanding of scientific concepts unless their practical application is also examined (see, for instance, Volfson et al., 2018, 2020).

While the classical clinical interviews and/or pen-and-paper questionnaires intended to examine students' understanding may seem dry and boring for some participants, sometimes even feeling as "doing a favor" for the researcher; DDCT are characterized by comfortable, interesting and even gaming atmosphere engaging the discussion. Therefore, conducting focus-group interviews as DDCT about physics concepts and their application for explaining real phenomena in the informal and unusual context of circus is of a potential to reveal ways of thinking, ideas and misconceptions which are absent today in the professional literature. Indeed, our preliminary study (Volfson et al., 2022) found out some new misconceptions regarding real situations involving circular motion. Thus DDCT engaging in the physics analysis of circus practices and devices can definitely be seen as a diagnostic setup enabling to examine how participants utilize what they have learnt in physics classes to explain real phenomena and situations. For instance, DDCT 2 revealed that some engineering students tend to consider moment of inertia as a result of *circular impetus force*, whereas others explain it by the means of *centrifugal force*. DDCT 4 diagnosed materialistic thinking of teacher 2 regarding heat transfer process. That is considering heat transfer as a direct process of "hot" molecules' flow from point 'A' to point 'B' (Chi et al., 2012; Volfson et al., 2019) instead of the scientifically correct understanding. This fact of declaring materialistic view of an actually emergent process by a senior science teacher points at the extreme robustness of such misconceptions (Chi, 2005; Chi et al., 2012; Volfson et al., 2019) and emphasizes the need of looking for new ways to arouse and treat such misconceptions. We discuss in the next section how DDCT can meet this need and facilitate conceptual change regarding physics concepts.

Instruction Aspect

First of all it should be emphasized that DDCT is an experiential way of bringing physics to the audience. Indeed, experiential learning is defined as "*… a philosophy and methodology in which educators purposefully engage with students in direct experience and focused reflection in order to increase knowledge, develop skills, and clarify values*" (AEE, 2011, para. 2). Dialogic discussions provide a wide stage for students' reflection focused on underlying physics principles explaining how circus tricks and equipment work while, circus master-classes (such as DDCT 2) enable direct phenomenological experience. As we have shown, DDCT cause the participants to be involved intellectually, emotionally and physically, which is of a potential to trigger positive changes on the level of the cognitive, affective and social acquisitions (Gorghiu & Ancuța Santi, 2016). Indeed, Young et al. (2008) report that experiential learning activities are likely to result in "… deeper approach to learning … and more favorable attitudes by students" (p. 38). This reinforces our belief that circus art and DDCT might offer a kind of cure for students' aversion to physics as reported for instance, by Baram-Tsabari and Yarden (2005) and Ornek et al. (2008).

As it was already explained above, discussions about circus tricks do not deal with pure "laboratory" demonstrations of physics phenomena but focus on the analysis of real situations–performing acrobatics/circus tricks and ways of circus props' work. Thus, integration of DDCT in physics teaching also meets the modern science teaching standards' requirements (ITEA, 2007; NGSS Lead States, 2017;

Superintendent of Public Instruction, 2018). Indeed, as our previous studies (Volfson et al., 2018, 2020, 2022), as well as the present study results show, a large part of the population–youth and adults–experience difficulties in correct application of physics concepts in the analysis of real situations. This fact reinforces even more the teaching standards arguments. According to Vosniadou et al. (2001), "When learning is situated in real-world context, what is learned is better remembered, and problem-solving skills become linked to situations similar to those likely to be used, this facilitating transfer" (p. 382). However, despite the call of the standards to integrate real-life and science, this integration is frequently absent from science classes. It is well known from the literature that it may be hard for teachers to apply new standards in practice. This is not surprising. The literature shows that implementing new standards pose a great challenge for teachers (Eshach & Schwartz, 2006; NGSS Lead States, 2013). Thus, DDCT due to the excitement and amazement that circus art stirs up, the visibility and experientialism; might be a good starting point for integrating circus contexts at least when teaching Newtonian mechanics, rigid body mechanics and heat theory.

Indeed, learning about circus tricks which are visually demonstrated and further can be experienced in master-classes is truly situated in a real-world context and thus might increase the chances that what students learn about the physics of a certain trick or device will be transferred to the analysis of other situations governed by the same physics principles. Thus, participants of DDCT 2, for instance, succeeded to utilize what they had learnt about moment of inertia and the First Newton Law relatively juggling rings, a spinning plate and poi in further analysis of the staff spinning technique; while in DDCT 3 students employed the knowledge about torque acting on a rolling trident to correctly explain the trick of bouncing the trident. Therefore, we believe that the integration of circus contexts with science might contribute not only to an understanding of these contexts per se but also to an understanding of general physics principles.

Second, exposing teachers to the barriers that students face in explaining circus tricks while the DDCT, might be of help to teachers, curriculum developers, and textbook authors to develop efficient learning materials (Eshach, 2009; Eshach & Schwartz, 2006; Galili & Hazan, 2000; Hrepic et al., 2010; Treagust, 2006; Volfson et al., 2018). For instance, the results of this study clearly show that educators should consider their students' tendency to use the *centrifugal force* misconception (DDCT 1 and 2), *circular impetus force* (DDCT 2) and *materialistic/direct* views of heat transfer (DDCT 4).

DDCT–Novel Direction in Dialogic Teaching

DDCT is actually a novel direction in dialogic teaching. Indeed, as examples 1-4 of DDCT show, each discussion is characterized by the IRPE pattern of interaction (Eshach, 2009). Let us explain this in more detail.

1. *Initiation*-demonstration of a trick/number and inspiring a discussion by a challenging question. For instance, *why did the water not spill? I fill hot; what heat is? How does heat propagate from the fire to my hand?,* etc.
2. *Responses*-the participants speak and the artist listens. Here participants reveal their own ideas, confront those ideas with other ideas, adopt or reject other ideas, create hybrid ideas, and sharpen their ideas (Eshach, 2009; Lehesvuori, 2013)
3. *Prompts*-the artist encourages participants to express their ideas, commends participants, sometimes, and if necessary asks for clarifications, sometimes provides challenging prompts and appropriate demonstrations widely using the suitable circus equipment. The artist's prompts can be roughly distinguished as
   (a) diagnostic–similarly to focus-group interviews, aiming at detection and identification of misconceptions (Krueger & Casey; 2000; Rabee, 2004; Volfson, 2018; Volfson et al., 2021, 2022; Wells & Arauz, 2006). For instance, "*When we throw up a juggling ring, we have to spin it with our palm. This spin is needed to stabilize the ring's trajectory in the air since every rotating body maintains its spinning axis. This is called moment of inertia. What is this moment of inertia? Why does it exist?*" (DDCT 2) and
   (b) prompts guiding towards the correct concepts by challenging misconceptions or scaffolding participants closer to their potential level of development (Lehsvuori, 2013). For instance, "*Ok! So if there is the centrifugal force and I spin a bowl and the rope suddenly tears, in what direction the bowl will fly?*" (DDCT 1). While the diagnostic prompts mostly aim at detection and identification of

misconceptions, prompts guiding towards the correct concepts aim at leading the learner to the desired conceptual change (Eshach, 2009).

4. *Evaluation*–Here the dialogue is over. The artist summarizes the discussion and presents the correct explanation or, if one of the participants has already said the correct answer, clarifies it.

Two patterns of DDCT were observed in the present study: *zigzag* and *concept tower* as specified by Eshach (2009). The *zigzag* between foci concepts conceptual flow structure is the place where concepts are adopted and debated by student groups or individuals (Eshach, 2009). This structure is mostly typical for audiences of naïve students and/or a diverse age population with a diverse physics background. See, for instance, DDCT 1 and 2. Indeed, in DDCT 1 the participants were adults and adolescents. However, the audience of DDCT 2 was engineering students which might arise some concerns regarding the last argument. Certainly, these students, as can be seen according to their answers (**Figure 11**), completed or were in the middle of a rigid body mechanics course and thus formally were familiar with the concepts of Newton laws, spinning axis, moment of inertia etc. They, however, did not succeed utilizing these concepts in the analysis of the discussed phenomena and devices. This is probably, because the students were not trained to do so and consequently could be seen in a sense as naïve, at least regarding the analysis of real-life phenomena and devices. This fact reinforces our findings in previous studies (Volfson et al., 2018, 2020, 2022) and support the call of the modern teaching standards to integrate formal science and real-life situations' analysis.

Another explanation for the *zigzag* pattern in certain DDCT might be that these DDCT were part of entertainment shows (in hotels and summer camps for example, but not at schools) and thus there was a competitive atmosphere. These conditions might have led the participants to focus more on new ideas to increase the chances that the artists will give them a prize, instead of aiming at deeply concentrating on one other's ideas so as to achieve deeper understanding. In such competitive cases (DDCT 1) coming up with novel idea and rephrasing others' ideas, were the most common types of responses. But it is not only the participants who contributed to this situation. The artist was also working under certain constrains like he did not want to turn the show into a physics lesson, but rather wanted the audience to feel they are in an entertainment environment. He therefore did not encourage the participants to contradict other participants' views, and indeed, the results show that the use of prompts confronting participants with their own ideas was quite low.

The *concept tower* pattern was observed in DDCT 3 and in a sense, in DDCT 4. According to Eshach (2009), the concept tower structure emerges when the participants are of a certain knowledge base in the discussion field and the problem is found in their ZPD. Here almost every new answer is the development of the previous one and thus students' ideas are employed "*as building blocks for the construction of new and more complex shared understandings*" (Eshach, 2009, p. 14). Indeed, the participants of DDCT 3 already were familiar with Newtonian mechanics and probably were trained in analysis of real-life situations; therefore, they could construct the correct understanding of the torque concept almost on their own with a light guidance of the teacher who was present in the show, and the artist. DDCT 4, on the contrary did not lead to the correct understanding but, provided an opportunity to flood and relate the materialistic misconception of heat. That is considering heat transfer as a direct process of "hot" molecules flow from point 'A' to point 'B' (Chi et al., 2012; Volfson et al., 2019) instead of the scientifically correct understanding. Familiarity with this kind of misconceptions enabled the artist to arise and identify this misconception. Actually, the first and the third prompts of the artist aimed to trigger the expression of this misconception and thus construct step by step the wrong model of heat transfer. Once it was stated, the artist refuted it and concluded the DDCT by presenting the correct idea.

To this end, can we claim that the participants actually learned physics in the DDCT? According to diSessa (1993), an expert's way of thinking is characterized by "a *sense of mechanism and involves those facts about the world that are true in more and more general circumstances as the physicist considers more and more universal and fundamental descriptions, ending with basic laws or principles that he or she holds always to be true*‖ (p. 107). For instance, an expert in rigid body mechanics is expected to start the analysis of every spinning prop knowing what moment of inertia and torque are; further estimating the moments of inertia for every spinning axis and appraising the forces and torques which have to be applied in order to operate the prop. The application of physics knowledge by an expert must be independent of the context of the problem being utilized in the same manner in every context (diSessa, 2018). Indeed, students who participated DDCT 2, where taught the concept of moment of inertia in the contexts of juggling rings and a spinning plate–generally, rotating rings and discs; and further were able to utilize this knowledge correctly in the context of the staff–generally, a rotating rod with masses on its edges. The participants of DDCT 3 learned the torque concept in the context of the rolling trident and were further able to apply it relatively bouncing the trident. That is, the participants succeeded to analyze rotating of the trident around another axis; also this situation visually looked quite different. In other words, the students succeeded transferring knowledge from one situation to another. These facts indicate a degree of learning while DDCT.

How can DDCT lead to conceptual change in the case of existing misconceptions (DDCT 1, 2, and 4)? According to the classical model of Posner et al. (1982) the following four conditions must be fulfilled for a conceptual change to occur. Let us see to what extent DDCT meet these conditions.

1. *Dissatisfaction with existing conceptions*–learners must collect a store of unsolved puzzles or anomalies which their current concepts cannot solve. The artist aiming to achieve this situation challenges and confronts participants with their own ideas mostly using circus equipment and/or performs appropriate tricks. For instance, regarding the view that the water does not spill from the bowls because it has no time since the speed of spin is high (DDCT 1), an idea that was connected mainly to vertical plane, the artist rotated the bowls in the vertical and the horizontal planes separately. He then challenged the participants by asking them to refer to the fact that in the horizontal movement there is "*more than enough time*" for the water to spill from the bowls. This helped the spectators to realize that the idea that the fast spin of the bowls cuts down the time of the water to spill out is not relevant in the case of horizontal movement and thus, is not correct. Further, the artist challenged the *centrifugal force idea* by spinning and releasing one of the bowls and emphasizing that "*if there was a centrifugal force, it had to pull the bowl outside …*" In the case that the artist could not find any "on place" contradicting demonstration, as it happened in DDCT 4 regarding the mean free path of air molecules, he just brought the known scientific data refuting the misconception.
2. *A new conception must be intelligible*–after dissatisfaction is achieved, the artist evaluates the answers and presents the correct explanation. He does it in such a manner that most participants are able to grasp how experience can be structured by a new concept sufficiently to explore the possibilities inherent in it. Therefore, the artist explains the correct concept first of all in lame terms and only further, if the audience is enough advanced, he develops more formal explanations.
3. *A new conception must appear initially plausible*–the artist emphasizes how the new concept is capable to solve the problems generated by its predecessors. He also underlines, if needed, the consistency of the new concepts with other fields of knowledge. For instance, when explaining the moment of inertia of a spinning plate, the artist emphasized that this tendency of rotating bodies to maintain their spinning axis is also the reason for why bicycles and motorbikes are more stable as we ride them.
4. A new concept should suggest the possibility of a fruitful research program-it should have the potential to be extended, to open up new areas of inquiry. The artist asked the participants to apply the new concepts/understanding achieved in the analysis of previous props/tricks to explain the next ones. For instance, in DDCT 2 after the analysis of the juggling rings and the spinning plate and developing the moment of inertia concept, the artist provided the opportunity to apply the novel knowledge in the analysis of the staff. In DDCT 3 the new trick of bouncing the trident was analyzed basing on the knowledge about torque developed in the previous inquiry of rolling the trident.

In order to go through these four steps, the teacher/artist providing DDCT needs to develop a repertoire of scenarios for identifying participants' ideas and facilitating the desirable conceptual change towards the correct understanding in DDCT about different physics concepts in the circus context. This means, first to study about the possible misconceptions in the relevant issues from literature and field experience; second, to develop a scenario–prompts and demonstrations–aiming at challenging these misconceptions. We bring an example of such scenario in **Appendix A**. It is worth to note that we do not suggest here DDCT as a kind of alternative for the classical physics teaching methods, but as a helpful and enriching extension. It is our belief that DDCT can also contribute to acrobatics and circus art teaching. This is to say, understanding of the physical principals which govern a certain exercise or trick can help an artist to better perform it, thus, contributing both, the artist's performance and safety (Donskoy & Shoyhet, 1981; Zharskih, 1965).

Research Limitations and Directions for Further Research

The present study brings the idea of integrating circus art and physics teaching in DDCT within formal as well as informal setups. However, the question, whether and to what extent the participants have learned physics in the DDCT remains open in a sense. Indeed, we can deduce about the possible products of learning basing on theoretical models of conceptual change (diSessa, 1993, 2018; Posner et al., 1982; Vosniadou et al., 2001; Yuruk, 2007;) and participants' answers in the discussions. All these indicate DDCT to be a promising approach in physics teaching. However, it definitely has to be further examined by diagnostic tools such as in-depth clinical interviews (Clement, 2000; Volfson, 2018) and inventories (knowledge tests and questionnaires) (Adams & Weimann, 2010; Janda, 2008) such as FCI (Hestenes et al., 1992), for example, provided pre- and post-DDCT activities. It also might be useful statistically comparing these inventories results among students who participated in DDCT, other enriching activities and a control group. The other course of action is developing new student-centered inventories basing on the misconceptions identified in the DDCT (Adams & Weimann, 2010; Volfson et al., 2018). Indeed, DDCT actually constitute a kind of focus group interviews and thus can be used as an effective instrument for investigation of students' thinking as our previous study has shown (Volfson et al., 2022). All these are the focuses of our next studies.

The present study has been provided in Israel and thus, it is limited to the Israeli population. It could be also worth full to run similar studies in other countries comparing to other groups of participants educated in other countries.

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REFERENCES

Adams, W. K., & Wieman, C. E. (2010). Development and validation of instruments to measure learning of expert-like thinking. *International Journal of Science Education, 33*(9), 1289-1312. https://doi.org/10.1080/09500693.2010.512369

AEE. (2011). *Association for Experiential Education*. http://www.aee.org/

Baram-Tsabari, A., & Yarden, A. (2005). Characterizing children's spontaneous interests in science and technology. *International Journal of Science Education, 27*(7), 803-826. https://doi.org/10.1080/09500690500038389

Ben-Abu, Y. (2018). A time for introducing the principle of least potential energy in high school physics. *Energies, 11*(1), 98. https://doi.org/10.3390/en11010098

Ben-Abu, Y., Wolfson, I., Eshach, H., & Yizhaq, H. (2018). Energy, Christiaan Huygens, and the wonderful cycloid–theory versus experiment. *Symmetry, 10*(4), 111. https://doi.org/10.3390/sym10040111

Chi, M. T. H. (2008). Three types of conceptual change: Belief revision, mental model transformation, and categorical shift. In S. Vosniadou (Ed.), *Handbook of research on conceptual change* (pp. 61-82). Erlbaum.

Chi, M. T. H., Roscoe, R. D., Slotta, J. D., Roy, M., & Chase, C. C. (2012). Misconceived causal explanations for emergent processes. *Cognitive Science, 36*, 1-61. https://doi.org/10.1111/j.1551-6709.2011.01207.x

Cobb, P. (1994). Where is the mind? Constructivist and sociocultural perspectives on mathematical development. *Educational Researcher, 23*(7), 13-20. https://doi.org/10.3102/0013189X023007013

Craig, C., You, J., Zou, Y., Verma, R., Stokes, D., Evans, P., & Curtis, G. (2018). The embodied nature of narrative knowledge: A cross-study analysis of embodied knowledge in teaching, learning, and life. *Teaching and Teacher Education, 71*, 329-340. https://doi.org/10.1016/j.tate.2018.01.014

Demirci, N. (2005). A study about students' misconceptions in force and motion concepts by incorporating a web assisted physics program. *TOJET: The Turkish Online Journal of Educational Technology, 4*(3), 7.

Dilshad, R. M., & Latif, M. I. (2013). Focus group interview as a tool for qualitative research: An analysis. *Pakistan Journal of Social Sciences, 33*(1), 191-198.

Ding, L., Chabay, R., & Sherwood, B. (2013). How do students in an innovative principle-based mechanics course understand energy concepts? *Journal of Research in Science Teaching, 50*(6), 722-747. https://doi.org/10.1002/tea.21097

diSessa, A. A. (1993). Toward an epistemology of physics. *Cognition and Instruction, 10*(2/3), 105-225. https://doi.org/10.1080/07370008.1985.9649008

diSessa, A. A. (2018). A friendly introduction to "knowledge in pieces": Modeling types of knowledge and their roles in rearning. In G. Kaiser, H. Forgasz, M. Graven, A. Kuzniak, E. Simmt, & B. Xu (Eds.), *Invited lectures from the 13th International Congress on Mathematical Education* (pp. 65-84). Springer. https://doi.org/10.1007/978-3-319-72170-5_5

Donskoy, D., & Shoyhet, K. (1981). Biomechanical justification of acrobatic exercises technique. In V. Korkin (Ed.), *Sportive acrobatics*. Fizkultura i Sport.

Ernest, P. (1993). Mathematical activity and rhetoric: Towards a social constructivist account. In N. Nohda (Ed.), *Proceedings of PME-17.* University of Tsukuba.

Eshach, H. (2009). Analysis of conceptual flow patterns and structures in the physics classroom. *International Journal of Science Education, 32*(4), 451-477. https://doi.org/10.1080/09500690802635247

Eshach, H., & Schwartz, J. L. (2006). Sound staff? Naive materialism in middle-school students' conceptions of sound. *International Journal of Science Education, 28*(7), 733-764. https://doi.org/10.1080/09500690500277938

Eshach, H., Lin, T., & Tsai, C. (2017). Misconception of sound and conceptual change: A cross sectional study on students' materialistic thinking of sound. *Journal of Research in Science Teaching, 55*(5), 664-684. https://doi.org/10.1002/tea.21435

Galili, I., & Hazan, A. (2000). Learners' knowledge in optics: Interpretation, structure and analysis. *International Journal of Science Education, 22*, 57-88. https://doi.org/10.1080/095006900290000

Gorghiu, G., & Ancuta Santi, E. (2016). Applications of experiential learning in science education non-formal contexts. In *Proceedings of the ICEEPSY 2016: 7th International Conference on Education and Educational Psychology* (pp. 320-326). https://doi.org/10.15405/epsbs.2016.11.33

Gurevich, Z. (1977). *About the genres of Soviet circus*. Art.

Halliday, D., Resnick, R., & Walker, J. (2014). *Fundamentals of physics*. Wiley.

Hestenes, D., Wells, M., & Swackhamer, M. (1992). Force concept inventory. *Physics Teacher, 30*, 141-158. https://doi.org/10.1119/1.2343497

Janda, L. H. (2008). *Psychological testing: Theory and applications.* The Open University.

Krueger, R. A. (1988). *Focus groups: A practical guide for applied research.* SAGE.

Krueger, R. A., & Casey, M. A. (2000). *Focus groups. A practical guide for applied research*. SAGE.

Lehesvuori, S. (2013). *Towards dialogic teaching in science challenging classroom realities through teacher education* [PhD dissertation, University of Jyvaskyla]. https://doi.org/10.5617/nordina.768

Ornek, F., Robinson, W. R., & Haugan, M. P., (2008). What makes physics difficult? *International Journal of Environmental & Science Education, 3*(1), 30-34.

Patton, M. Q. (1990). *Qualitative evaluation and research methods*. SAGE.

Perelman, Y. I. (1994). *Entertaining tasks and experiments*. VAP.

Ponnambalam, M. (2012). Popularization of physics–the Jamaican experience. *Latin America Journal of Physics Education, 6*, 390-393.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211-227. https://doi.org/10.1002/sce.3730660207

Rabee, F. (2004). Focus-group interview and data analysis. *Proceedings of the Nutrition Society, 63*, 655-660. https://doi.org/10.1079/PNS2004399

Roche, J. (2001). Introducing motion in a circle. *Physics Education, 36*, 399. https://doi.org/10.1088/0031-9120/36/5/305

Roth, W. M. (1995). Affordances of computers in teacher-student interactions: The case of interactive physics™. *Journal of Research in Science Teaching, 32*, 329-347. https://doi.org/10.1002/tea.3660320404

Rowlands, S., & Graham, T. (2005). What is conceptual change in mechanics? In D. Hewitt, & A. Noyes (Eds.), *Proceedings of the 6th British Congress of Mathematics Education* (pp. 144-151).

Rowlands, S., Graham, T., Berry, J., & McWilliam, P. (2007). Conceptual change through the lens of Newtonian mechanics. *Science & Education, 16*, 21-42. https://doi.org/10.1007/s11191-005-1339-7

Samovarski, S. (1987). *Physics thought coming into being.* Bialik Institute.

Schlender, S. (2013). *Scientist circus performers make physics fun*. https://www.voanews.com/a/scientist-circus-performers-make-physics-fun/1632653.html

Scott, P. H., Mortimer, E. F., & Aguiar, O. J. (2006). The tension between authoritative and dialogic discourse: A fundamental characteristic of meaning making interactions in high school science lessons. *Science Education, 90*, 605-631. https://doi.org/10.1002/sce.20131

Scott, P., & Ametller, J. (2007). Teaching science in a meaningful way: Striking a balance between 'opening up' and 'closing down' classroom talk. *School Science Review, 88*, 77-83.

Superintendent of Public Instruction (2018). *Educational technology learning standards: Grades 9-12*. Washington, DC.

Volfson, A. (2013). Safe and correct grouping. *Wingate Institute*. https://www.wingate.org.il/Index.asp?ArticleID=6288&CategoryID=267

Volfson, A. (2018). *Physics behind acoustical devices: Development of a diagnostic instrument for examining the understanding of the underlying physics principles explaining how simple acoustic apparatuses work* [PhD dissertation, Ben-Gurion University].

Volfson, A., Eshach, H., & Ben-Abu, Y. (2018). Development of a diagnostic tool aimed at pinpointing undergraduate students' knowledge about sound and its implementation in simple acoustic apparatuses' analysis. *Physical Review Physics Education Research, 14*, 020127. https://doi.org/10.1103/PhysRevPhysEducRes.14.020127

Volfson, A., Eshach, H., & Ben-Abu, Y. (2019). Introducing the idea of entropy to the ontological category shift theory for conceptual change: The case of heat and sound. *Physical Review Physics Education Research, 15*, 010143. https://doi.org/10.1103/PhysRevPhysEducRes.15.010143

Volfson, A., Eshach, H., & Ben-Abu, Y. (2020a). Identifying physics misconceptions at the circus: The case of circular motion. *Physical Review Physics Education Research, 16*, 010134. https://doi.org/10.1103/PhysRevPhysEducRes.16.010134

Volfson, A., Eshach, H., & Ben-Abu, Y. (2020b). When technology meets acoustics: Students' ideas about the underlying principles explaining simple acoustic devices. *Research in Science Education, 51*, 911-938. https://doi.org/10.1007/s11165-019-09913-w

Volfson, A., Eshach, H., & Ben-Abu, Y. (2021). Preliminary development of a simple statistical tool for estimating mental model states from a diagnostic test. *Physical Review Physics Education Research, 17*, 023105. https://doi.org/10.1103/PhysRevPhysEducRes.17.023105

Volfson, A., Eshach, H., & Ben-Abu, Y. (2022). History of science based dialogues on sound waves: From sound atoms to phonons. *Physical Review Physics Education Research, 18*, 010123. https://doi.org/10.1103/PhysRevPhysEducRes.18.010123

Vosniadou, S. (2013). Conceptual change in learning and instruction: The framework theory approach. In S. Vousniadou (Ed.), *International handbook of research on conceptual change* (pp. 11-30). Routledge.

Vosniadou, S., Ioannides, C., Dimitrakopoulou, A., & Papademetriou, F. (2001). Designing learning environments to promote conceptual change in science. *Learning and Instruction, 11*, 381-419. https://doi.org/10.1016/S0959-4752(00)00038-4

Vyas, P. (2012). Misconception in circular motion. *International Journal of Scientific & Engineering Research, 3*, 12.

Vygotsky, L.S. (1978). *Mind in society: The development of higher psychological processes.* Harvard University Press.

Weisberg, S., & Newcombe, N. (2017). Embodied cognition and STEM learning: Overview of a topical collection in CR:PI. *Cognitive Research: Principles and Implications, 2*(38), 1-6. https://doi.org/10.1186/s41235-017-0071-6

Wells, G. (1999). Putting a tool to different uses: A reevaluation of the IRF sequence. In G. Wells (Ed.), *Dialogic inquiry: Towards a sociocultural practice and theory of education* (Chapter 5). Cambridge University Press.

Wells, G., & Arauz, R. M. (2006). Dialogue in the classroom. *Journal of the Learning Sciences, 15*(3), 379-428. https://doi.org/10.1207/s15327809jls1503_3

Young, M., Caudill, E. M., & Murphy, J. W. (2008). Evaluating experiential learning activities. *Journal for Advancement of Marketing Education, 13*, 28-40.

Yuruk, N. (2007). A case study of one student's metaconceptual processes and the changes in her alternative conceptions of force and motion. *EURASIA Journal of Mathematics, Science & Technology Education, 3*(4), 305-325. https://doi.org/10.12973/ejmste/75411

Zharskih, M. (1965). *Study the effectiveness of various instructional methods for teaching children 7-12 years acrobatic exercises* [PhD thesis, The State Pedagogical Institute in Voronezh].

APPENDIX A

Participants' misconceptions about circular motion in the spinning of bowls show and dialogic scenario for their revision as brought in DDCT 1.

The preliminary study findings indicate the presence of the following three misconceptions about circular motion in the context of the bowls' show: *centrifugal force*, *speed of spin,* and *air pressure* (Volfson et al., 2022; DDCT 1). How can DDCT facilitate the process of conceptual change towards the correct concepts? diSessa (1993), as well as Chi (2008) and some other researchers do not propose much hope for revising misconceptions by simply telling the students which explanatory concepts are the correct ones as we usually do in frontal teaching but rather suggest to "…compare and contrast their existing conception and new ideas, recognize, integrate and evaluate existing and new conceptions and associated commitments, everyday experiences and contextual factors" (Yuruk, 2007, p. 306). The artist, who was familiar with these studies, constructed his pedagogic approach on DDCT in the same way. The following scheme (**Figure A**) concludes the main three misconceptions' occurrences via DDCT as presented above and the appropriate pedagogic techniques of the artist to confront them. We hope that physics educators will find it helpful.

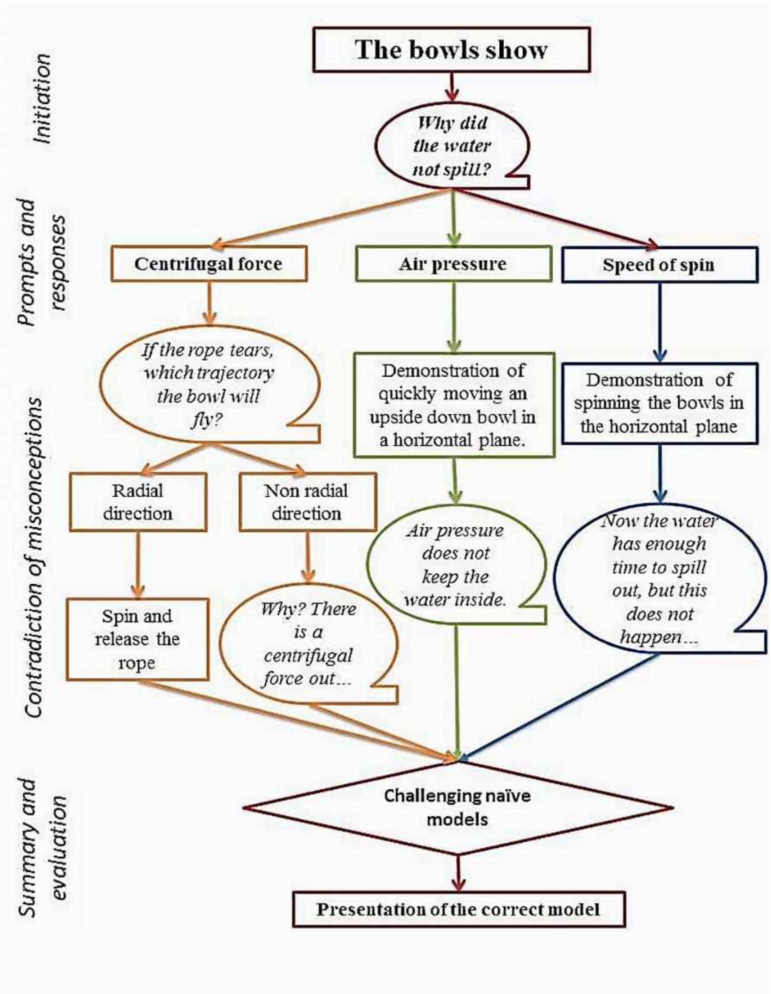

Figure A. *S*cenario aiming at challenging misconceptions about circular motion in the bowls show & guiding towards the scientifically correct understanding (Source: Authors' own elaboration)