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DEVELOPMENT AND TESTING OF THE DTSICM MODEL: A DESIGN THINKING STRATEGY TO IDENTIFY AND CLEAR MISCONCEPTIONS IN SCIENCE

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Abstract: Failure to use the appropriate methods to identify and clear misconceptions remains a major hurdle in students' understanding of scientific concepts and the transformation of the lay public into informed citizens with the appropriate scientific knowledge, skills and attitudes required to face current and future challenges such as climate change, emergence of new epidemics, food shortages, and energy crisis. This has been expounded by the lack of a proper umbrella strategy that provides a structured, formalized, and adaptable pathway which allow teachers to select and use the most appropriate context-driven methods to identify and clear misconceptions. This study therefore showcases the development of a new context-driven adjustable model, termed the 'Design Thinking Strategy to Identify and Clear Misconceptions' (DTSICM), which is based on the 5-staged Stanford model of 'design thinking'. The model, centered around evidence-based decision making, provides teachers with an adjustable pathway that allow selection of methods that are context-appropriate and fit the needs of students. Underpinned by mixed methodology, the study showcased the efficiency of the DTSICM model by revealing a net reduction in the percentage prevalence of misconceptions held by the sampled students on the scientific concept of photosynthesis.

Keywords: misconceptions, design thinking, model, strategy, science learning

Introduction

Misconceptions, though indiscriminately present in all disciplines, remain very common in science, as scientific concepts are related to our daily life events and experiences (Nguyen & Rosengren, 2004), are often abstract mental representations of the world and its natural phenomena (Yates and Marek, 2014), and can be complex, and elusive (Rouvray, 1992). Analysis of the literature revealed that all the five main types of misconceptions, namely preconceived notions, non-scientific beliefs, conceptual misunderstandings, vernacular, and factual misconceptions affect the correct understanding of scientific concepts impacting on students' academic performance and exam grades (Chen, Sonnert, Sadler, Sasselov & Fredericks, 2020), which according to Smyth and Hannan (2006) explains students' disinterest towards the science subjects and their consequent drop-out during the subject choice exercise. Though the causes of students' disinterest towards science are multifold including loaded syllabi, unadapted curriculum, and use of inappropriate teaching and learning strategies, this paper

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focuses on the identification and clearing of misconceptions which researchers considered as one of the major factors of students' disinterest toward science.

The scholarship around misconceptions in science showcases how several researchers such as Tekkaya (2002), Gooding and Metz, (2008), Maraş & Akman, (2009),and Kurt, Ekici, Aktas, & Aksu (2013) have investigated the use of several methods and techniques to identify and clear misconceptions such as the elicitation methods, word association tests, prediction-observation and explanation (POE), concept mappings, drawings, classroom debates, laboratory and computer-based instruction, conceptual change texts, project-based learning (PBL) and field work. However, Lassonde, Kendeou and O'Brien (2016) and Engida (2019) highlighted that some misconceptions are persistent and tend to reappear despite the use of these methods, which was explained by Wandersee, Mintzes, & Novak (1994) and Duit &Treagust (1998) who stated that a method which has been successfully used in a specific context may not work in another context. In fact, teachers' failure to use appropriate context-based methods to identify and clear students' misconceptions remains an important cause of the reappearance of resistant misconceptions. Thus, teachers need not only identify students' misconceptions, but also comprehend the source and type of the particular misconceptions so that selection of methods to clear the misconceptions are contextualized-driven and appropriate. This study therefore design, develop and test the DTSICM (Design Thinking Strategy to Identify and Clear Misconceptions) model as an umbrella strategy that provides teachers with a structured, formalized, and adaptable pathway to select and use the most appropriate context-driven methods to identify and to clear misconceptions.

Misconceptions: Definition, types, origin, and persistence

Any conception which is inconsistent or in discordance with scientific theories (Yip, 1998) are termed 'misconceptions' or 'alternative conception' (Kurt, Ekici, Aktas, & Aksu, 2013), 'misunderstanding' (Kılıç & Sağlam, 2009), 'non-scientific conceptions' (Cinici, 2013) or 'informal ideas' (Mak, Yip & Chung, 1999).

Essentially, there are five main types of misconceptions, namely (i) preconceived notions, which are popular conceptions rooted in everyday experiences, (ii) non-scientific beliefs, which are views learned by students from sources other than scientific foundations, such as religious or mythical teachings (iii) conceptual misunderstandings, which students construct to deal with their confusions that occurred they are taught scientific information in a way that does not provoke them to confront paradoxes and conflicts resulting from their own preconceived notions and non-scientific beliefs, (iv) vernacular that are derived from the use of words that mean one thing in everyday life and another in a scientific context, and (v) factual misconceptions, which are erroneous facts encountered during childhood and interactions with family members, parents, teachers, and even textbooks (Brown and Clement, 1991; Cuse, 1997; Marshall, 2003; Suprapto, 2020).

As far as the sources of misconceptions are concerned, Barras (1984) and Sanders (1993) explained that misconceptions find their origin from factors related to learners, teachers, and resources. According to Sanders & Cramer (1992) and Dhindsa & Treagust (2014), learner-related misconceptions commonly originate from (i) learners' inability to link new concepts or ideas to existing ones due to the absence of required prior knowledge and prerequisites, (ii) learners' differences in cognitive capabilities, competencies, interests, potential, and experiences, and (iii) the everyday language or learners' maternal tongue. Teacher related misconceptions are commonly associated with the traditional classroom settings, where teachers are considered as the sole provider of knowledge. Mak, Yip & Chung (1999), Sanders (1993) and Gudyanga & Madambi (2014), Al-Balushi, Ambusaidi, Al-Shuaili, & Taylor (2014) and Pekmez, (2018) explained that misconceptions often passed from teachers to learners through a slip of the tongue, an incomplete or inaccurate answer to students' question, use of incorrect analogies to explain biological concepts, compartmentalization of concepts, or use of inappropriate teaching and conceptual change strategies. Gudyanga & Madambi (2014) and Nyachwaya & Wood, (2014) explained that resources, such as books, educational websites, science project books, and curriculum guides, may also potentially mislead educators and students leading to misconceptions. For instance, use of old textbooks containing information which are outdated and in discordance with new research and concepts represents a main source of misconceptions.

Among the common misconceptions, some are considered persistent or resistant to change. Sanders (1993) defined such misconceptions as the incorrect mental constructs that are firmly held by the learner and resilient to change, Arnaudin & Mintzes (1985) highlighted that such misconceptions as tenacious, and Ozgur (2013) explained that despite the use of conceptual change strategies, such misconceptions tend to reappear and cannot be totally overcome. The reason for this situation might be that some factors have been ignored or were not realized.

Strategies to identify and clear misconceptions

The scholarship around misconceptions showcases several common methods used to identify students' misconceptions such as interviews (Bahar, Johnstone, & Hansell, 1999), concept maps (Bahar, 2003), drawings and concept cartoons (Keogh, Naylor, and Downing, 2003; Köse, 2008), and 'concept test' or worksheets which include open-ended, simple multiple choice, two-tier multiple choice, or Likert type questions (Haluk Ozmen ,2007; Gulbin & Gamze 2015). Similarly, several methods used to clear misconceptions were also identified such as the word association tests (Kurt, 2013; Kurt, Ekici, Aktas & Aksu, 2013), prediction-observation and explanation (Wiji and Mulyani, 2018), concept mappings (Köse, 2007; Tekkaya, 2003), drawings, writings and concept cartoons (Kurt, Ekici & Aktas, 2013; Kusumaningrum, Ashadi & Indriyanti, 2018), classroom debates, laboratory and computer based instruction (Maraş & Akman, 2009), conceptual change texts (Akyürek & Afacan, 2013), analogy and modelling (Brown & Clement, 1989; Dilber & Duzgun, 2008), dual situated learning model (Hwa and

Karpudewan, 2017; Kurniawan, Rahayu and Fajaroh, 2020), and mind map (Chavan and Patankar, 2016).

These techniques or methods of identifying and clearing misconceptions are often mutually used in strategies or approaches such as the ‘conceptual change strategy (CCS)’, which allow teachers to engage students transforming their misconceptions into new and scientifically accepted concepts. The CCS, with a constructivist underpinning principle, involves (i) evaluation of one's knowledge to notice inconsistencies (Otero, 1998), (ii) confronting the inconsistencies so that learners experience dissatisfaction with the initial knowledge (Posner, Strike, Hewson, & Gertzog, 1982) and (iii) developing appropriate teaching resources and activities to clear the misconceptions and construct new knowledge (Yürük, 2000; Dhindsa & Anderson, 2004). Figure 1 below shows a variant of the Conceptual change model (Stepans, 2003) which was originally proposed by Posner, Strike, Hewson & Gertzog, (1982).

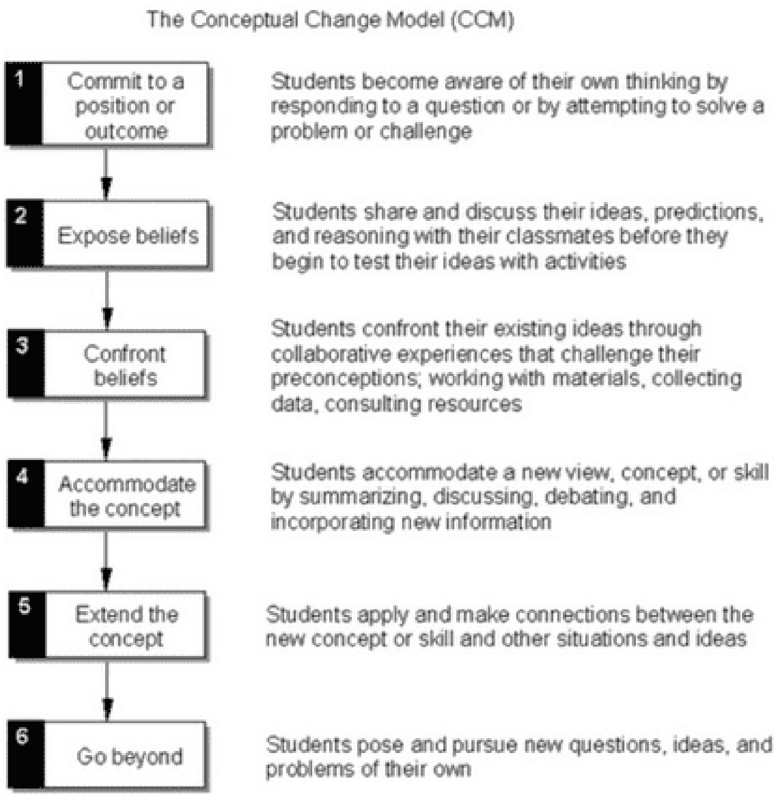

Figure 1: The Conceptual Change Model (Stepans, 2003)

However, analysis of the scholarship around CCS revealed that through several researchers, including Hewson & Hewson (1983), Ünal (2007), Samsudin, Suhandi, & Rusdiana (2016), Üce & Ceyhan (2019) have indicated that CCS is an effective strategy to identify and clear misconceptions, others have differently positioned themselves, highlighting the following limitations of CCS:

• *Effectiveness of CCS has not been empirically and significantly evidenced in the literature*

Kumandaş, Ateskan and Lane (2018), through a meta-synthesis study, revealed that though many articles showcased the use of CCS to clear misconceptions, only few studies have thoroughly tested the efficiency of the strategy.

• *CCS is not context based.*

Though CCS model provides opportunities to mutually use different methods to identify and clear misconceptions, it does not provide the needed structure for teachers to select the most appropriate methods based on context specificity and students' needs. For instance, Lehman, Carter & Kahle (1985) indicated that 'concept map' is not an efficient method of clearing misconceptions in science, whereas Okebukola and Jegede (1988) stated that that it is not an efficient method. In fact, the efficiency of a specific method depends on the context, specificities, types and sources the misconceptions.

• *CCS is not efficient in clearing resistant/persistent misconceptions.*

It has been shown in the literature that despite confronting students with their misconceptions during the linear process of CCS, some misconceptions persist. The CCS with a linear model, lacks the cycling structure needed to ensure that alternative methods are used until the persistent misconceptions are ultimately cleared. In fact, the CCS has been showcased as an efficient strategy to clear non-resistant vernacular and factual types of misconceptions but ineffective in clearing 'preconceived notions', and 'non-scientific beliefs', which are way more challenging (Vosniadou, 2001). Such misconceptions are often resistant as they are rooted in past experiences, are derived from religious or mythical teachings, or are often interlinked and connected to many other beliefs and notions (Gardner & Dalsing, 1986; McCutcheon, 1991).

• *CCS is not grounded into the origin and sources of misconceptions.*

Another limitation is that CCS focuses on clearing misconceptions without prior analysis of the sources and types of misconceptions. According to Higbee & Clay (1998) a strategy becomes efficient only if the origin and evolution of the misconceptions are properly understood.

Without, undermining the use of other strategies that are currently being used to identify and clear misconceptions, this study showcases the efficiency of using the DTSICM as a strategy that offers teachers with the needed support and formalised structure to identify and clear misconceptions. Moreover, this study adds to the existing scholarship around misconceptions, a new strategy to identify and clear misconceptions.

Theoretical Framework

The ‘Stanford model of design thinking’ (Haso-Plattner Institute, 2011), adapted from Plattner, Meinel and Weinberg’s (2009) ‘design thinking framework’, as shown in figure 2, was used as the underpinning theoretical lens to guide the development of the DTSICM model which provide teachers with a structured pathway to identify and clear students’ misconceptions based on the constructivist approach.

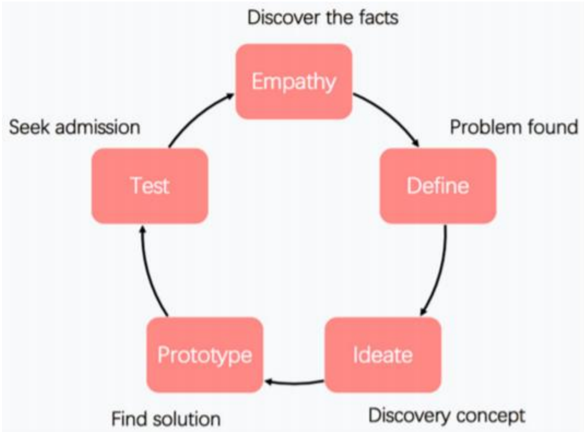

Figure 2: The 2011 Stanford Model of Design thinking

The 5 stages of the ‘Standford model’, as depicted in figure 2, has been described by Henriksen *et al*. (2017), as follows:

Empathise: During this first stage, designers gather data about the users through observation and interaction. This allows the designers to approach the problem from the point of view of the user, eliminating self-bias and increasing the probability of correctly identifying the issue.

Define: Based on information gathered during the first stage, designers come up with a problem statement to guide the following steps. This statement considers the user and the context in addition to the underlying problem.

Ideate: In the third stage, designers come up with ideas and possible solutions. It is important that during ideation, designers are allowed to work without constraints so they can think of novel creative ideas that go beyond traditional methods.

Prototype: In the fourth stage, at least one idea is chosen out of all those generated during ideation. This is not the final solution but a concrete model that can be used during the next stage.

Test: In the fifth stage, testing is carried out to put the prototype to use and to collect feedback following the implementation of the prototype. The feedback is vital since there is no indication as to the effectiveness of the prototype at solving the problem. However, if all steps have been properly carried, the prototype should work to a certain degree.

Analysis of the literature revealed that though the ‘design thinking approach’ has been successfully used as a strategy to transform the constructivism theory into action by researchers such as Scheer, Noweski and Meinel (2012) and Author (2021), it is believed that the approach has a broader potential in the field of education, which has not yet been tapped. This study showcases how the ‘Stanford model of design thinking’ may be used as a theoretical lens to further the use of ‘design thinking approach’ as a strategy which offers teachers the needed support through a formalised process to identify and clear misconceptions.

Methodology

The research design, underpinned by the ‘Stanford model of design thinking (2011)’, has a mixed epistemological stance consisting of the designing of the DTSICM model and testing its efficiency as case studies, as depicted in figure 3.

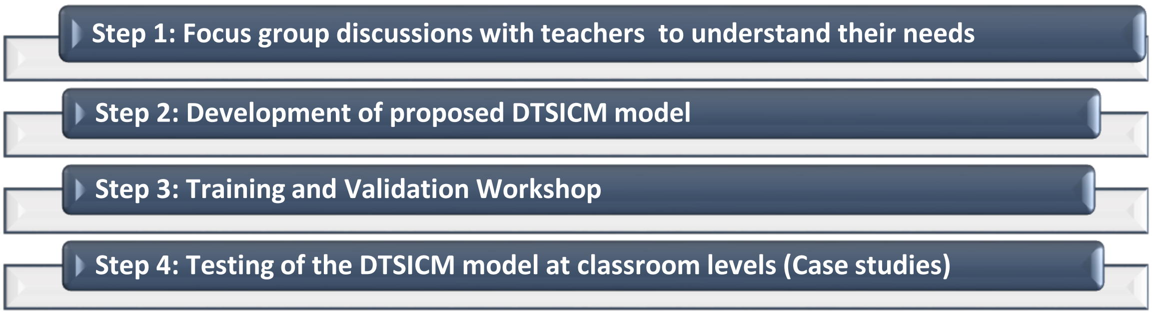

Figure 3: Research design

The first step, with a purely qualitative stance using Focus Group Discussion (FGD), captured the views of selected science teachers on the challenges and opportunities of identifying and clearing students’ misconceptions in science. A purposive sampling procedure was used to capture the voices of 16 science teachers and the selection was mainly based on the teachers’ potential of engaging in the debate. The teachers, representative of both public and private secondary schools from the four existing educational zones in Mauritius, were ex-PGCE (Post graduate Certificate in Education) students having a good record in their professional engagement at classroom level.

In step 2, the data obtained from the analysis of transcripts derived from Step 1 was used by the researcher to design and develop a proposed model (DTSICM) based on the needs of teachers. In step 3, a training and validation session was organized to present the model, capture participants views and feedback, to eventually validate the amended and finalized version of the DTSICM model. In the last step, the teachers tested the model in identifying and clearing misconceptions at classroom level as case studies. The data were then used to study the efficiency of the DTSICM model in practice.

Results and discussions

Table 1 shows the results of the thematic analysis of participants voices during the FGD on challenges and opportunities of identifying and clearing misconceptions.

Table 1: Voices of teachers on challenges and opportunities of identifying and clearing misconceptions

Key Verbatim data extract	**Overarching ideas guiding development of the model**	**The proposed model should therefore:**
Most science teachers in Mauritius still use the traditional lecture methods instead of the constructivist approach where students are engaged in constructing knowledge.	Traditional lecture against constructivist approach	Be based on constructivist learning theory
Lessons are not prepared based on diagnostic evaluation situating students' prior knowledge and prerequisite testing.	Diagnostic evaluation/prior knowledge/prerequisite	Allow teachers to develop their diagnostic tools
As teachers, we do not like prescriptive measures and prefer to own the process of change.	Agent of change	Allow teachers to decide on the methods to be used
Most teachers are not even aware that they also hold misconceptions like the students and are often the vector of the misconceptions	Teacher as vector of misconceptions	Allow teachers to confront teachers their own misconceptions
Most science teachers have been trained on the pedagogy of teaching and learning science as most have completed their PGCE.	Pedagogical training	Be based on the assumptions that teachers are pedagogically trained
To become the agent of change, we need to be motivated and most importantly convinced.	Motivation and conviction	Motivate teachers
Time is a major constraint as teachers are	Time constraint	Feasible in relation to time
I have tried some methods to clear students' misconceptions. Some are efficient and some not.	Efficiency of methods to clear misconception	Allow use of effective methods
There are so many methods of identifying and clearing misconceptions that often I don't know which one is most appropriate for my students.	Appropriateness of methods	Allow teachers to select the most appropriate methods
Some of the methods are not appropriate to identify and clear misconceptions. Despite using these methods, the students still hold the misconception I wanted to clear.	Method appropriateness Resistant misconception	Allow use of methods to clear resistant misconceptions
The more I tried to clear some of the misconceptions, more confused the students are and this led to more misconceptions	Creation of new misconceptions	Allow unlearning of wrong concept to create the correct concept. Allow selection of the most appropriate and context-driven methods
I think that after identifying students' misconceptions, as teachers we need to select wisely which method we will use to clear misconception. The methods should be based on my students' needs and context and not on ease only.	Selection of methods	
As teachers, we need to have a list of all common misconceptions that students usually hold on a topic, which may be used to identify whether my students hold the same misconceptions.	List of common misconceptions	Allow identification of students' misconceptions based on list of common misconceptions
We need to have a tool to rapidly and efficiently identify students' misconceptions	Efficient methods of identifying misconceptions	allow teachers to efficiently identify students' misconceptions
The methods used to clear misconceptions should cater for all students and not only for few. All students have the right to meaning teaching and learning and no one should be left behind.	Students' rights	allow clearing misconceptions of all students concerned.

Taking into consideration the voices of the teachers, the DTSICM model was developed, proposed to the teachers, discussed, and amended accordingly so that the model is owned by the teachers. The finalised DTSICM, as depicted in figure 4, provides a formalized, structured, and adjustable pathway allowing teachers to select and use the most appropriate context-driven methods to identify and to clear misconceptions. The DTSICM model, based on the 5-staged of Stanford model of 'design thinking', engages students in five decisive stages namely 'emphasize', 'define', 'ideate', 'prototype' and test'.

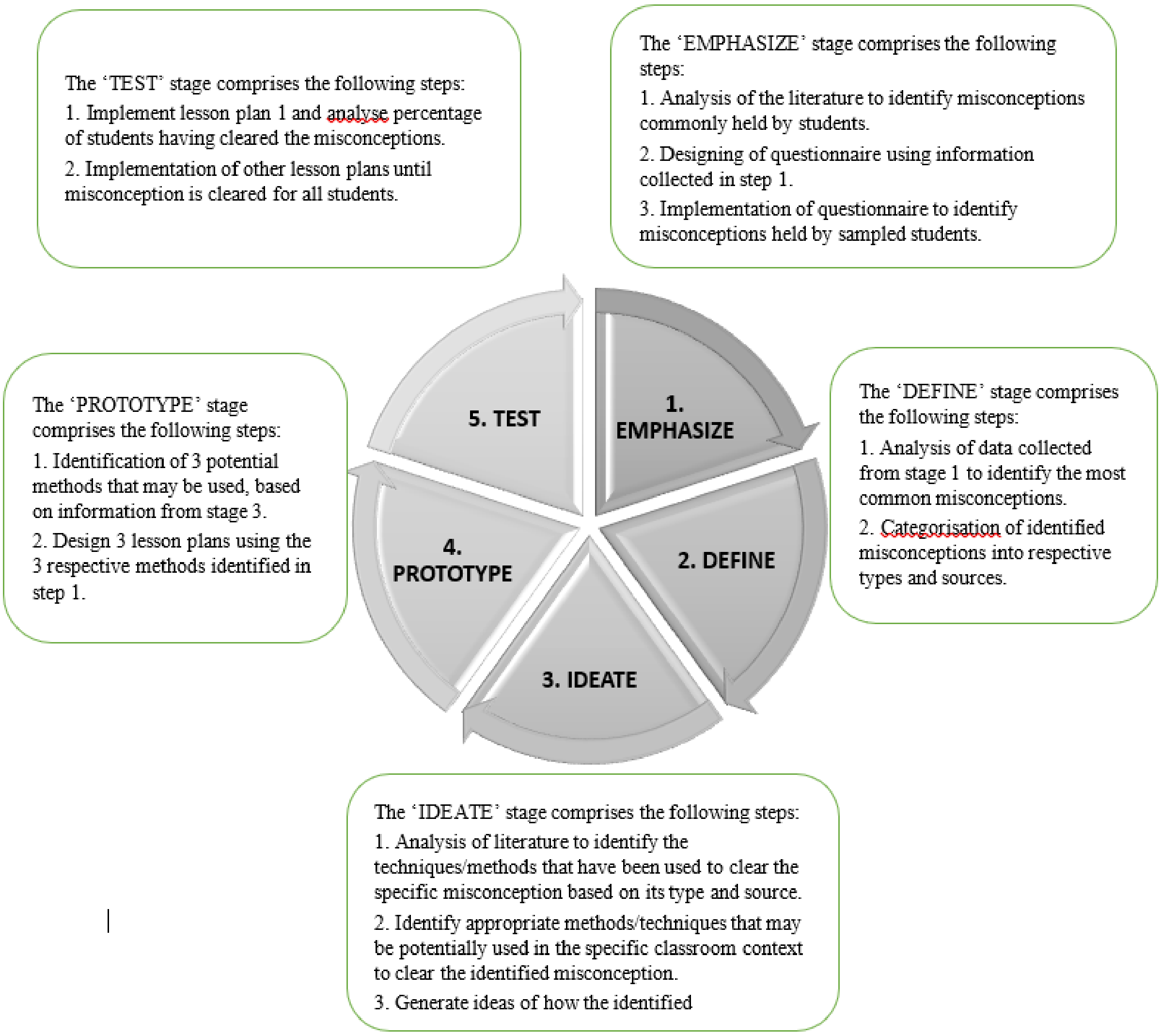

Figure 4: The DTSICM model

Once the DTSICM model was finalized by the teachers, it was tested at classroom level as a case study to test the efficiency of the model. During stages 1 and 2 of the DTSICM model, the most prevalent misconception held by the sampled students on photosynthesis, that is 'photosynthesis is the reverse of respiration', was identified. Figure 5 shows five different prototypes based on five different teaching and learning methods that were selected on the basis of their appropriateness to clear the specific misconception.

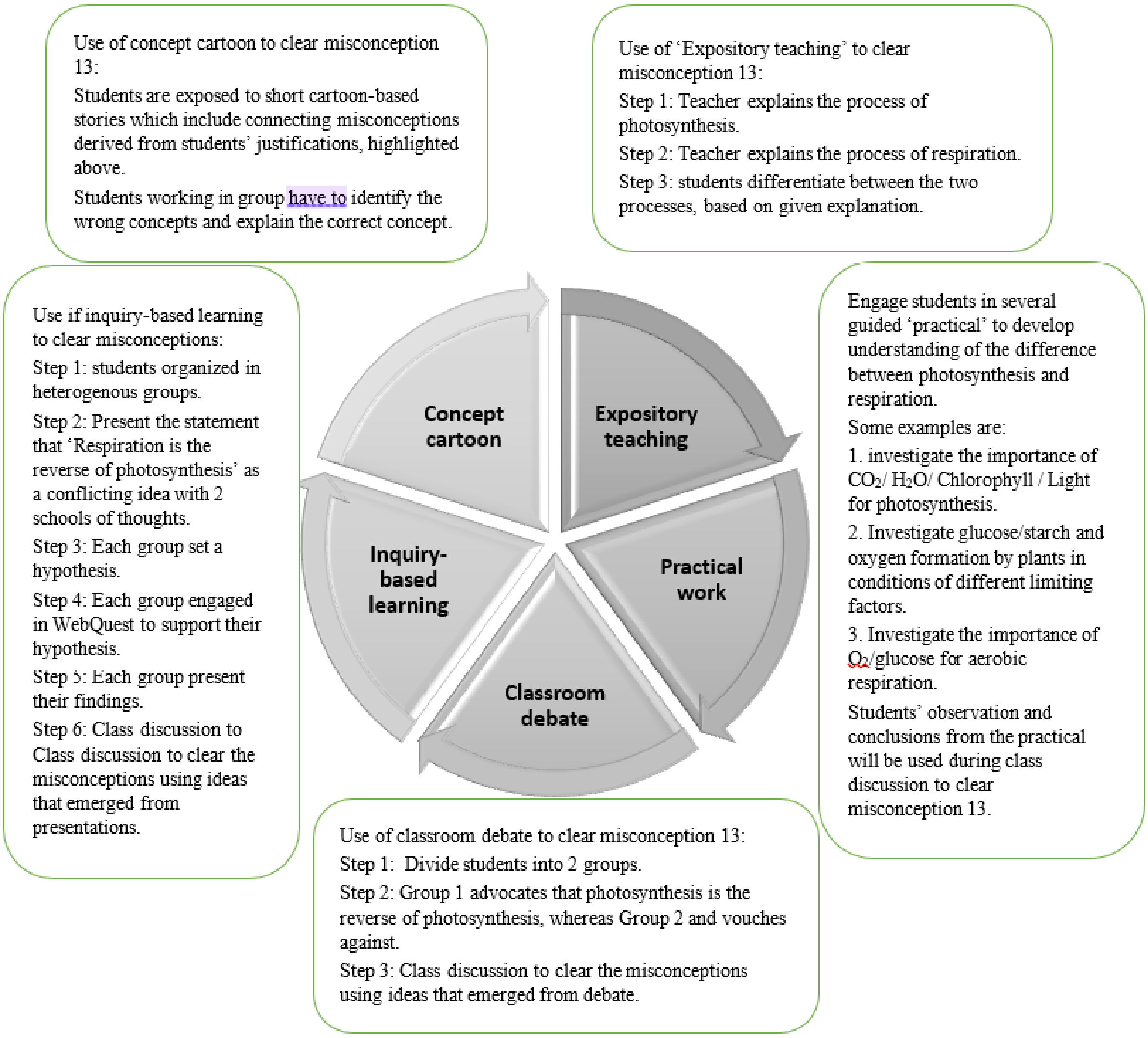

Figure 5: Use of DTSICM model to clear misconception: Photosynthesis is the inverse of respiration.

The prototypes were then implemented at classroom level to test the efficiency of the model in identifying and clearing misconceptions. Figure 6 shows the percentage of students who successfully cleared their misconceptions.

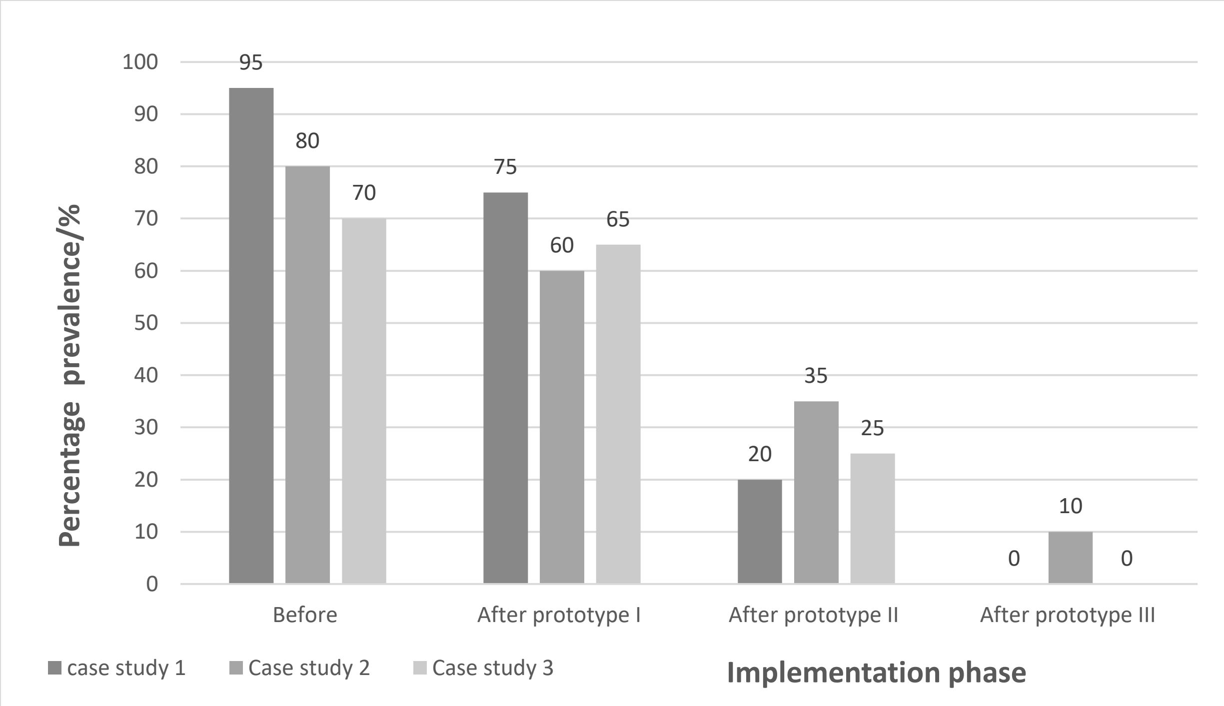

Figure 6: Efficiency of the DTSICM in science

Figure 6 shows a net decrease in the percentage prevalence of the identified misconception when implementing the prototypes. Though the methods used were different, they were selected on the basis of students' needs, types and sources of misconception to be cleared. This explained the efficiency of this model in providing teachers with the opportunities to use context-driven and need appropriate methods in clearing students' misconceptions.

These observations show that in a class of mixed abilities where students have different academic capabilities, learning styles, interests, aptitudes, skills and attitudes, a single method does not fit all. And in line with the concepts of 'education for all', 'reaching out all', 'inspiring every child' and 'no child left behind' which are policies and goals guiding the educational reform in Mauritius, the DTSICM model based on design thinking provides a structured and contextualized pathway where 100% clearance of misconceptions may be attained. The strategy caters for the needs of every student independent of their differences.

Conclusion

The findings, based on both qualitative and quantitative data analysis, showcase the efficiency of the DTSICM model, which offers educators the needed support through a formalised process to identify and clear students' misconceptions. In fact, the developed DTSICM model (i) is context-oriented, (ii) is underpinned by the constructivist student-centered approach, (iii) caters for the analysis of each misconception in terms of its types and origins, (iv) uses different prototyped lessons based on specificity of misconception to be cleared, (v) allows data-informed ideation and selection of the most appropriate methods to clear a specific misconception, (vi) ensures that percentage prevalence of misconceptions is reduced to minimum by using alternatives ideated methods of clearing misconceptions, (vii) ensures full engagement of teachers and students in the process, (viii) provides a structured pathway which may be easily replicated in other educational contexts and settings, (ix) benefits both teachers and students in improving or restructuring their conceptions of specific scientific concepts, and (x) is appreciated by all participants.

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