The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #43039

Predictors and Mediators of Conceptual Change: A Systematic Literature Review

Mr. Olanrewaju Paul Olaogun, University of Georgia

Olanrewaju Paul Olaogun holds a Ph.D. in Engineering from the University of Georgia, Athens, GA, USA. He received his BSc. degree from the University of Benin, Nigeria and MSc. degree from the Florida Institute of Technology in Electrical Engineering. His research interest is focused on knowledge conceptualization and conceptual change. He has also worked extensively in the areas of students' motivation, achievement goals, engagement, technology mediated learning and academic belonging.

Dr. Nathaniel Hunsu, University of Georgia

Nathaniel Hunsu is an assistant professor of Engineering Education. He is affiliated with the Engineering Education Transformational Institute and the school of electrical and computer engineering at the university. His interest is at the nexus of the res

Predictors and Mediators of Conceptual Change: A Systematic Literature Review

Abstract

Students have misconceptions about almost every subject, particularly those that are complex and counterintuitive. These misconceptions have been copiously reported in literature. Conceptual change is the process by which students change their misconceptions to a more scientifically correct conception. A growing number of studies have examined predictors and mediators of conceptual change. However, there is a paucity of research that has systematically synthesized these studies to assess the viability of the variables and to point to key variables that scholars need to focus on. Furthermore, understanding the processes of conceptual change is important for addressing deeply rooted misconceptions that students bring to the classroom. In this work in progress, we searched academic journals databases for articles in January of 2023 and 299 research articles were identified out of which 14 of them met the inclusion criteria and were analyzed for this systematic review. The results show different categories of predictors and mediators of conceptual change including affective, motivational, and self-regulation variables. The implication of this study is also discussed.

1.0 Introduction

Misconceptions about basic scientific concepts often stem from students' innate need to make sense of the phenomena they encounter in their daily lives [1]-[4]. It is common for learners to develop naïve theories that help them interpret their experiences of the world. Such theories, built up over time, are often in conflict with consensus opinion in the scientific community. Students may also acquire misconceptions from misunderstanding their teachers and from the textbooks they read – both sometimes are the sources of misconceptions [5], [6].

Like any theory, misconceptions (naïve theories) enable students to explain their realities, and predict what could be, even if falsely. As such, they tend to be held strongly and are not readily abandoned once acquired. In fact, theorists have proposed that instruction that engender conceptual change must intentionally highlight students' misconceptions and provide intelligible alternative ideas to get students to abandon their misconceptions [7], [8]. The process by which misconceptions are remediated or replaced with scientifically accurate views is called conceptual change in the educational and learning science literature [9]. Conceptual change is described as the process of restructuring inaccurate mental models [10]-[12]. The typical instruction involves the transmission of knowledge to fill gaps in learners' prior knowledge with missing details. However, the conceptual change instruction seeks to achieve a 'radical transformation' or restructuring of the learners' prior conceptions to ensure they acquire a more coherent and scientifically correct mental model of a subject [13],[14].

Due to the complexity of conceptual change processes, several researchers have examined different factors that predict or mediate it. Predictors are variables that explain the variability in the outcome or dependent variable while mediators are variables that explain the process by which a third variable influences the relationship between the dependent variable and the independent variable. The main objective of mediation analysis is to identify and explicate the mechanism underlying the relationship between the predictor and an outcome variable through a mediator [15]. In mediation analysis, both the direct effect and the indirect effect can be assessed statistically, enabling researchers to test complex relationships and interactions [16].

While several prior studies have examined the cognitive and affective mechanisms that underlie conceptual change learning [17], [18], there has been no effort to synthesize the literature for researchers to know which variables work and through which mechanisms or under which condition the effect is sustained. Additionally, understanding the factors that predict or mediate conceptual change is crucial for designing effective educational interventions and promoting meaningful learning outcomes. Furthermore, findings from this review could inform empirical studies that may help us understand the predictive and mediational roles of non-cognitive factors on engineering students' conceptual change. This study aims to conduct a systematic review of the literature to identify and analyze the predictors and mediators of conceptual change across various domains.

2.0 Theoretical Background

Extant conceptual change literature indicates that many students' often have robust and deeply rooted misconceptions that can be resistant to being changed by the typical instructional approach [19]. Misconceptions are often subtle and oblivious to students, and even instructors may be unaware of the misconceptions that their students bring to the class [20]. Unaddressed misconceptions can undermine the efficacy of instruction of scientific concepts and inhibit learning. While many misconceptions have no significant implication for learning, some other misconceptions may have unforeseen implications for correct application of scientific knowledge. For example, untenable engineering judgments that stem from a seemingly benign misconception may have adverse effects on the design and implementation of some engineering solutions. A vivid example was the collapse of Florida International University pedestrian bridge where six people died and ten injured [21] which may be attributed to bad engineering judgment due to misconceptions. As such, instructions that target misconceptions and promote conceptual change learning are invaluable to acquiring correct scientific knowledge and skills.

2.1 Relevant models of conceptual change learning

The conceptual change model (CCM): Theorists have proposed several models of conceptual change learning [22], [23]. Posner and colleagues proposed the conceptual change model (CCM) in their seminal work on knowledge revision. They posited that conceptual change involves a radical change in learners' prior knowledge that is similar to the paradigm shift in theory change described by Kuhn [24]. The CCM proposes that four conditions – dissatisfaction, intelligibility, plausibility, and fruitfulness – are essential to facilitating conceptual change in learners who have misconceptions. According to Posner et al, instruction must first stimulate cognitive conflict that causes learners to become dissatisfied with their prior conception. A cognitive conflict occurs when the learners' preconception or naïve explanation no longer provide a satisfactory explanation to a phenomenon or concept. This makes them seek a more intelligible and plausible alternative explanation. Apart from being cognitively dissatisfied, the new message must be intelligible, that is, it must be comprehensible and intelligible to the learner to be considered a good replacement for their preconception. In addition to being intelligible, the new conception must be plausible: i.e., it must be seen or perceived as being a reasonable alternative. Lastly, Posner, et al. [24] argued that the alternative perspective must be fruitful – i.e., it must have the potential of resolving the cognitive conflict and dissatisfaction that the learner has experienced with their preconception.

Several interventions that aim to resolve students' misconceptions have drawn on the propositions of the CCM. One example of such intervention is the use of refutation texts in scientific literature. Refutation texts are designed to draw the reader's attention to a misconception by expressly stating it as a misconception that many people often have about the subject. Next, the text presents anomalous data or an alternative perspective that is intended to create a cognitive dissonance and dissatisfaction about the faulty preconception in the reader [25].

2.2 Alternative models of conceptual change learning:

Pintrich and his colleagues argue that motivational and affective variables affect whether students can identify and acknowledge their misconceptions and whether they will revise their prior knowledge [26], [27]. They argued that a better portrait of the conceptual change process would be one that seriously considers the roles of motivation variables such as task value, goal orientation, and self-efficacy belief in conceptual change learning [27]. They described Posner's conceptual change model as focusing on 'cold concepts' and argued that a 'warm conceptual change' model must consider the effects of affective and non-cognitive variables on learning for conceptual change.

Researchers have proposed conceptual change models that incorporated the recommendations of Pintrich and his colleagues work, that is, models that account for cognition, affect, and motivation. For example, Dole and Sinatra [28] proposed the Cognitive Reconstruction of Knowledge Model (CRKM) as a model of conceptual change learning that integrates both cognitive and motivational variables, in explaining how conceptual change learning occurs. In addition to the CCM position on the need for stimulating cognitive dissatisfaction, the CRKM highlights the roles of personal relevance, social context, and need for cognition in stimulating or inhibiting learning for conceptual change. The CRKM also argues that certain learner and message characteristics can interact in ways that increase the likelihood that knowledge revision or conceptual change will occur. Learner characteristics may include prior knowledge and learners' mental and emotional commitment to such prior knowledge and learning motivation. The likelihood that conceptual change learning will occur may depend on how coherent learners' prior conceptions are, and whether they have any deep emotional commitments to their ideas. For example, preconceptions that seem very logical and well coherently connected in learners' minds, and for which they passionately support, are less likely to succumb to the 'tyranny' of fact and data. Similarly, motivation and commitment to learning can determine whether learners will be objective in examining their cognitive commitments and in considering whether to revise an inaccurate preconception. The CRKM model suggests that factors such as personal relevance, need for cognition, achievement goal orientations, and social contexts are all factors that could determine whether learners will experience cognitive dissatisfactions with their preconception and revise the prior knowledge.

Lastly, the CRKM model also posits that certain message characteristics can make learners consider alternative perspectives as more appealing, offering better explanation for a phenomenon they had misconceived. For conceptual change to occur, Dole and Sinatra [28] argue that not only should a new conception be intelligible and plausible, but it must also be comprehensible and rhetorically compelling. The CRKM model hypothesizes how the interactions between 'warm' variables of learning may influence conceptual change. However, it does not predict conditions under which conditions strong, weak, or no conceptual change would occur as seen in Table 1. Furthermore, there has been scant empirical validation of the major propositions of the model.

Table 1. CRKM Model of Conceptual Change [25]

Learner characteristics	**Message characteristics**
Existing conceptions	Comprehensible
Motivation: Dissatisfaction	Coherent
Motivation: Personal relevance	Plausible
Motivation: Social context	Rhetorically compelling
Motivation: Need for cognition	
Learner engagement	
Low engagement	High engagement
No/weak conceptual change ↔	Strong conceptual change

2.3 Purpose of the Study

Since the seminal work of Posner and the follow up study by Pintrich, several studies have examined the roles of cognitive, motivational, and affective factors on knowledge revision. This current study aims to synthesize findings from these various studies to determine the variables that influence conceptual change and their relative effectiveness. Specifically, this systematic review aims to achieve the following objectives:

a. Identify the main categories of factors that predict conceptual change or knowledge revision.
b. Identify the main categories of factors that mediate conceptual change or knowledge revision.
c. Evaluate the importance and significance of predictors and mediators of conceptual change or knowledge revision.
d. Identify theoretical framework and models used to explain the predictive and mediational process of conceptual change or knowledge revision.

Research Questions:

a. What are the descriptive patterns of the studies conducted?
b. What are the major predictors of conceptual change and how have they been conceptualized?
c. What are the major mediators of conceptual change and how have they been conceptualized?
d. What are the theoretical and methodological considerations of the included studies?

3.0 Method

For this review, we followed established guidelines for conducting systematic literature reviews and meta-analysis [29] and the PRISMA guidelines [30]. While the PRISMA was primarily developed and used for healthcare intervention research, many of the items on the checklist apply to educational research as well. By following the established guidelines and the PRISMA checklist, we can objectively and transparently report the findings of our systematic literature review.

3.1. Selection criteria and search strategies

To begin with, we developed a set of criteria to determine studies that should be included for coding and eventually for analysis and synthesis based on our preliminary review of predictors and mediators of conceptual change. To be considered eligible for inclusion for this systematic review, studies need to meet the following inclusion and exclusion criteria. The study:

a. examines misconceptions or knowledge revision.
b. uses quantitative methodology.
c. examines at least one mediator variable.
d. includes conceptual change or knowledge revision as outcome variable.
e. is published in peer review article.
f. is accessible online.
g. is written in English language.

Exclusion criteria include:

a. studies where conceptual change acts as predictor or moderator variable.
b. studies written in language other than English.
c. dissertation, thesis, grey literature, magazine and so on are all excluded.

All research designs that lend themselves to quantitative methodology are considered. The studies could be observational, experimental, or quasi-experimental studies. As long as there is a predictor variable and at least one mediator variable present in the design, the study would be included.

3.2 Literature Search

We conducted the literature search by searching through relevant databases. We searched Medline, Science Direct, Academic Search Complete, ERIC, PsycINFO, and Web of Science. In order to get the optimum result of our search efforts, we used keywords from key articles examining the predictive and mediating factors on conceptual change. The keywords “conceptual change”, “misconceptions”, “pregnan”, “predict*”, “mediat*” were used to identify relevant studies in the databases. Search term included these keywords joined together by Boolean operators e.g. (”conceptual change” OR misconceptions or mediat* OR predict* NOT pregnan*). This search yielded 299 articles across the databases. Initial search results contain 63 duplicate articles which were removed. After screening the title and abstract, 213 articles were removed, and the remaining 23 articles were retrieved for full text reading. After the full text reading, 9 articles that did not qualify based on the inclusion and exclusion criteria were removed. And the remaining 14 articles were included in this systematic review as depicted in Fig. 1

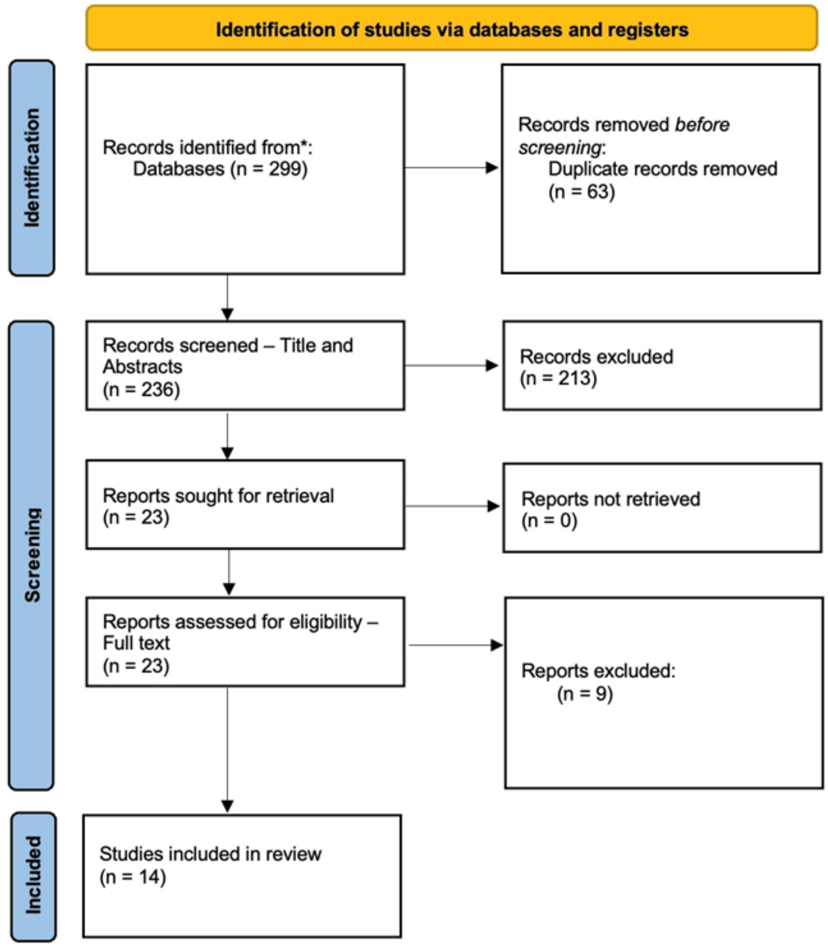

Fig. 1 PRISMA flow diagram showing the structural diagram of the study screening and selection processes.

3.3 Coding and study features

A coding sheet was designed to extract important and key features of the studies included. This excel sheet was organized into different sections: (1) reference information (2) study information (3) theoretical underpinning (4) participant information (5) methodological features (6) independent variables (7) mediating variable (8) dependent variable (9) Correlations and effect sizes (10) Findings (11) Major contributions and limitations. The first author coded 50% of the articles included in this study twice at different times to check the consistency of the coding. Intra-rater reliability at first was 89%, however, after resolving all areas of discrepancies, the intra-rater reliability was 98%. All the remaining articles were then coded. The second author went over the coding sheet to ensure the accuracy of the coding.

4.0 Results

This review presents comprehensive analysis of articles focusing on predictors and mediators of conceptual change. Our study involved a thorough review of 14 articles aiming to gain insights into variables that have been explored as predictors and mediators of conceptual change. It was observed that 79% of the studies were conducted between 2010 and 2022, and only one study was conducted before 2000. Figure 2 shows the distribution of published articles across the years.

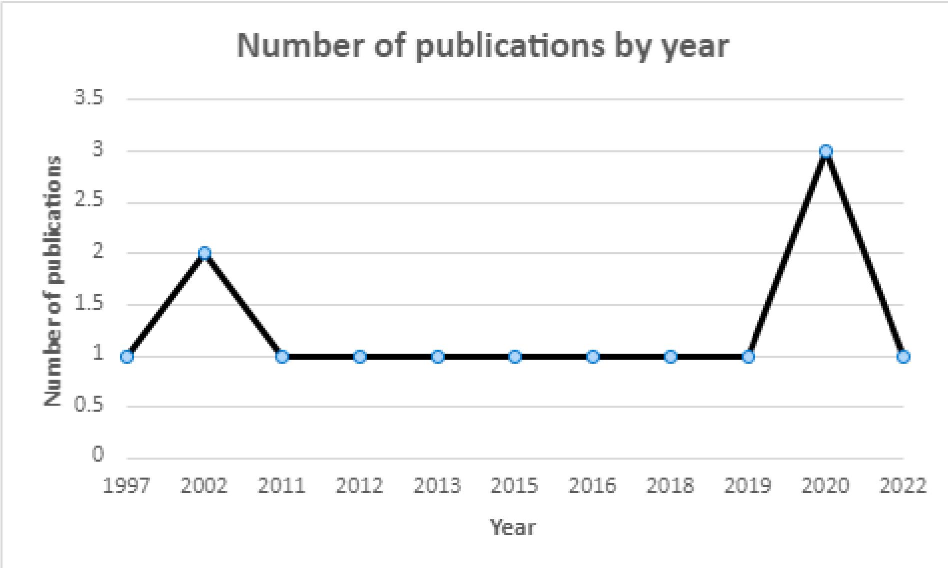

Fig 2. Number of publications by year.

Misconceptions cut across all age groups and school levels. Regarding the target participants of the studies coded, about 71% of the articles were conducted using undergraduate students – Figure 3. 14% of the articles worked with high school students while 7% of the coded articles worked with middle school and 5th grade students. Most of the studies used samples ranging from 100 to 200 participants. Our observation showed that the next most common sample sizes are those above 200, while only two studies used participants that were less than 100. The total number of participants were 3209, out of which 648 were female. The participants were from different learning domains with Physics and Biology dominating, while Light and vision, natural selection, Newton's first and second laws, and common cold were topics commonly explored for possible misconceptions.

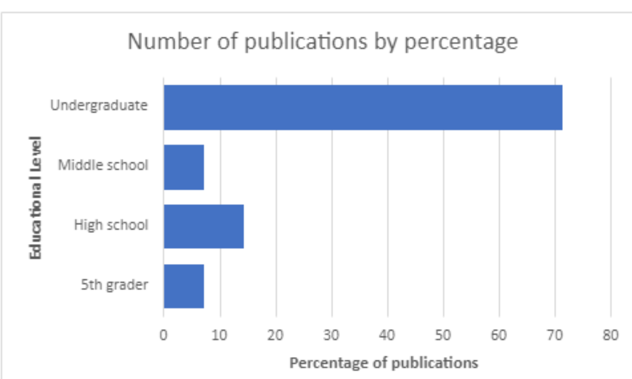

Fig 3. Number of publications by educational level.

Because of the nature of the questions explored in this review and the inclusion and exclusion criteria applied, most studies in this realm are done using either correlation, regression, path analysis, and structural equation modeling. All the analyses method mentioned fall under the category of quantitative, correlational studies.

Our next observation was the journal outlets where studies investigating predictors and mediators of conceptual change have been published. The analysis results show that most of the studies were published in either educational psychology outlets or science journal outlets. Two of the studies were published in contemporary educational psychology journal with impact factor of 10.3, others were published in relevant and high impact factor journals, see Table 2.

Table 2. Journal outlets and their impact factors

Row Labels	**Number of Studies**	**impact factor**
BRITISH JOURNAL OF EDUCATIONAL PSYCHOLOGY	1	3.7
COGNITION AND INSTRUCTION	1	3.3
CONTEMPORARY EDUCATIONAL PSYCHOLOGY	2	10.3
INSTRUCTIONAL SCIENCE	2	2.5
INTERNATIONAL JOURNAL OF SCIENCE AND MATHEMATICS EDUCATION	1	2.2
Issues in Theory and Practice	2	10.3
JOURNAL OF EDUCATIONAL PSYCHOLOGY	2	4.9
JOURNAL OF EXPERIMENTAL EDUCATION	1	2.2
JOURNAL OF RESEARCH IN SCIENCE TEACHING	1	3.9
LEARNING AND INSTRUCTION	1	6.2

Most of the work in this area has been conducted in the US, Canada, Germany, and Taiwan. It was noted that almost all the studies were conducted in developed countries. One of the studies did not report on the country where it was conducted. This is shown in Figure 4.

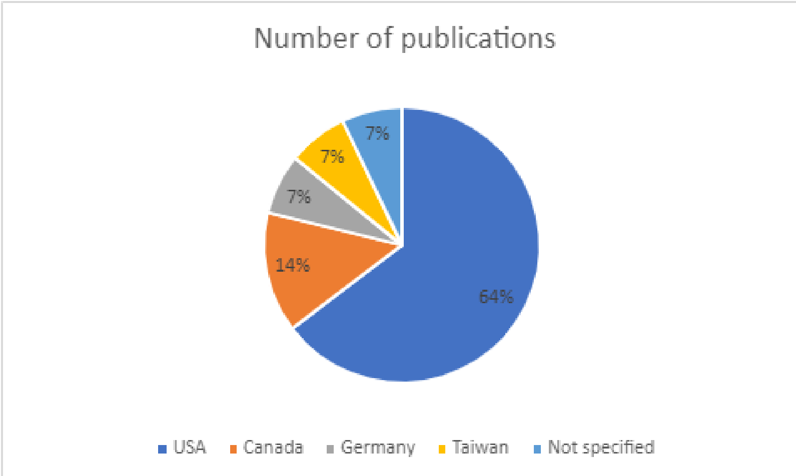

Figure 4. Countries of research studies (%).

Different theoretical lenses are used to study predictors and mediators of conceptual change. The most common one being the Cognitive Reconstruction of Knowledge Model (CRKM) theory that explains how message characteristics as intelligibility, coherence, plausibility and students' characteristics such as motivation interact to engage the learner in the learning task. The assumption in CRKM model is that if learners are highly engaged in a conceptual text, they would experience cognitive conflict, and that would lead to conceptual change. Other theories used to understand conceptual change include the achievement goal theory, Control value theory, Self- efficacy theory, and Interest theory.

4.1 Predictors of Conceptual Change

Our analysis reveals several predictors of conceptual change. These predictors fall into different categories including achievement goal orientations, motivation, affect and self-regulation and cognitive constructs. Taasoobshirazi and Sinatra [31] in their study of physics undergraduate students' misconceptions found that approach goal had small but significant effect on conceptual change. Similarly, Ranellucci, et al. [32] found that the adoption of mastery goal positively predicted conceptual change, while both performance approach and performance avoidance goals negatively predicted conceptual change. Furthermore, in an empirical study of tested approach goals. Linnenbrink and Pintrich [33] showed that mastery goal predicted conceptual change learning of projectile motion, that is, it helped students overcome their misconceptions. Motivational factors such as situational interest, individual interest, task value have also been examined as predictors of conceptual change. Our analysis shows that need for cognition, cognitive conflict and individual interests have conflicting results within the literature. While some researchers have shown that they predicted conceptual change, others have found no effect or even negative effects. For example, Taasoobshirazi and Sinatra [31] in a study of physics students found that need of cognition had small but significant influence on conceptual change, while in a follow up study, need for cognition was not a significant predictor of conceptual change. Thomas and Kirby [34] also found similar results that showed need for cognition as a significant predictor of conceptual change. Furthermore, they found that both situational interest and individual interests were significant predictors of conceptual change, however, the effect of situational interest on conceptual change is larger than that of individual interest.

Affective and self-regulation constructs have also been investigated as predictors of conceptual change. Constructs such as confusion, curiosity, and enjoyment, and attention allocation. In our analysis, affective factors of confusion, curiosity, and enjoyment have been studied as predictors of conceptual change. Taasoobshirazi, et al. [35] found that enjoyment significantly and indirectly predicted conceptual change through approach goals, motivation, and deep cognitive engagement. In their study, Muis, et al. [36] found that student's curiosity and confusion that followed from a surprise affects their engagement which led to conceptual change. These studies showed the importance of emotional constructs in the processes of conceptual change. In their study, Jones, et al. [37] found that attention allocation contributed significantly to student cognitive engagement that predicted the likelihood of conceptual change happening. These studies showed the importance of emotional and self-regulation constructs in the processes of conceptual change.

4.2 Mediators of Conceptual Change

As in the case of predictors of conceptual change, our analysis reveals several mediators of conceptual change. These mediators fall into different categories including motivation, affect, self-regulation, and engagement variables. Mediators explain the observed relationships between predictors and outcome variables. Two studies assessed students' motivation as a composite multidimensional construct comprising of student scores on task relevancy, self-determination, self-efficacy, intrinsic motivation, extrinsic motivation together and named it motivation [31], [35]. The results from their study show that need for cognition was an important construct and that its effect was mediated by students' motivation. Similarly, researchers have also examined deeper processing strategies, such as reflective thinking, are associated with the level of cognition necessary for conceptual change learning [38]. Our analysis revealed that most mediational processes of conceptual change are facilitated by students' cognitive engagement to the task.

The result of the analysis of the included studies shows that various self-regulatory constructs have been examined as mediators of conceptual change. Self-regulation constructs of attention allocation, critical thinking, elaboration, and strategy use have all been explored. In the study of Muis, et al. [36], critical thinking skill significantly mediated the effect of curiosity on conceptual change. And finally, affective factors play key mediational role in knowledge reconstruction. In their study of student misconceptions about genetically modified food GMF, Thacker, et al. [39] found that the emotions of curiosity, frustration, hope, and enjoyment play significant mediational roles in attitude and knowledge change. In particular, they found confusion mediated the relationship between pre-reading attitude and post reading knowledge. Similarly, Linnenbrink and Pintrich [33] in their investigation of the role of motivational beliefs on conceptual change conducted two studies. Findings from the first study showed that mastery goals had significant effect on conceptual change, however, the mediational role of affect on conceptual change was not significant. In a replication study with different participants, they found that only negative affect partially mediated the relationship between mastery goal and conceptual change of projectile motion [33].

5.0 Conclusion

This systematic review was undertaken to investigate predictors and mediators of conceptual change. This study investigated patterns of studies conducted to examine predictors and mediators of conceptual change. Also, we identify key predictors and mediators of conceptual change and evaluate their relative importance and significance in the process of knowledge construction and reconstruction. Furthermore, we categorize these variables in a way that can aid the development of instructional interventions to correct students' misconceptions, particularly in fields where misconceptions are prevalent like engineering.

Findings from our analysis show that motivational constructs of need for cognition, cognitive conflict, and individual interest have inconsistent results in terms of their predictive significance. For example, some studies found that need for cognition is necessary for conceptual change, while other studies have shown that it was not significant predictor of conceptual change[31], [35]. On the other hand, mastery goal and situational interest were consistent significant predictors of conceptual change. Similarly, affective factors of enjoyment and surprise resulting from curiosity and confusion were also significant predictors of conceptual change. These findings are important as they help instructors provide targeted interventions for remediating student misconceptions.

Finally, engagement variables such as cognitive engagement or learning strategies were consistently investigated as mediators of conceptual change. Understanding the factors that mediate a relationship is important to know if the effect of a predictor on conceptual change is direct or indirect through another variable. This knowledge is important for instructors to understand the best way to bring about conceptual change among their students. Instructors thinking about helping students to overcome their misconceptions can incorporate technology-enhanced learning tools, such as interactive simulations and digital platforms which can foster students' engagement and facilitate conceptual change[40]. Furthermore, the integration of generative learning strategies of self-explanation activities can enhance students' cognitive engagement and deepen their understanding of engineering concepts[41].

References

[1] J. Gooding and B. Metz, "From Misconceptions to Conceptual Change," *Science Teacher,* vol. 78, no. 4, pp. 34-37, 04/01/ 2011. [Online]. Available: https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,shib&db=eric&AN=EJ921657&site=ehost-live&scope=site&custid=uga1

http://www.nsta.org/publications/browse_journals.aspx?action=issue&id=10.2505/3/tst11_078_04.

[2] P. Mulhall, B. McKittrick, and R. Gunstone, "A perspective on the resolution of confusions in the teaching of electricity," *Research in Science Education,* vol. 31, no. 4, pp. 575-587, 2001.

[3] O. P. Olaogun, J. M. Foster, Z. Lin, A. Al Weshah, K. Yao, and N. J. Hunsu, "Determination of Students' Misconceptions using the Electric Circuit Concept Diagnostic (ECCD) Instrument," in *2023 IEEE Frontiers in Education Conference (FIE)*, 2023: IEEE, pp. 1-5.

[4] O. P. Olaogun, A. Skelton, M. Zafar, N. J. Hunsu, and I. A. Idowu, "A Systematic Review of Student Misconceptions about Electricity and Electric Circuit Concepts," in *2023 IEEE Frontiers in Education Conference (FIE)*, 2023: IEEE, pp. 1-5.

[5] G. Liu and N. Fang, "Student misconceptions about force and acceleration in physics and engineering mechanics education," *Int J Eng Educ,* vol. 32, no. 1, pp. 19-29, 2016.

[6] B. Sreenivasulu and R. Subramaniam, "University students’ understanding of chemical thermodynamics," *International Journal of Science Education,* vol. 35, no. 4, pp. 601-635, 2013.

[7] J. P. Smith III, A. A. DiSessa, and J. Roschelle, "Misconceptions reconceived: A constructivist analysis of knowledge in transition," *The journal of the learning sciences,* vol. 3, no. 2, pp. 115-163, 1994.

[8] J. H. Wandersee, J. J. Mintzes, and J. D. Novak, "Research on alternative conceptions in science," *Handbook of research on science teaching and learning,* vol. 177, p. 210, 1994.

[9] S. Vosniadou, "Conceptual change research: An introduction," in *International Handbook of Research on Conceptual Change*: Routlege, Taylor and Francis, 2013, pp. 1-8.

[10] C. A. Chinn and W. F. Brewer, "The role of anomalous data in knowledge acquisition: A theoretical framework and implications for science instruction," *Rev Educ Res,* vol. 63, no. 1, pp. 1-49, 1993.

[11] P. K. Murphy and L. Mason, "Changing knowledge and beliefs," 2006.

[12] S. Vosniadou, "Conceptual change research: State of the art and future directions," *New perspectives on conceptual change,* pp. 3-13, 1999.

[13] M. T. Chi, "Three types of conceptual change: Belief revision, mental model transformation, and categorical shift," *International handbook of research on conceptual change,* vol. 61, p. 82, 2008.

[14] N. Hunsu, K. Yao, A. Al Weshah, O. Olaogun, and S. Wang, "Work in Progress: The Electric Circuit Concepts Diagnostic (ECCD)," in *2022 ASEE Annual Conference & Exposition*, 2022.

[15] W. Wang and J. M. Albert, "Estimation of mediation effects for zero‐inflated regression models," *Statistics in medicine,* vol. 31, no. 26, pp. 3118-3132, 2012.

[16] D. Tingley, T. Yamamoto, K. Hirose, L. Keele, and K. Imai, "Mediation: R package for causal mediation analysis," 2014.

[17] S. Hadjiachilleos, N. Valanides, and C. Angeli, "The impact of cognitive and affective aspects of cognitive conflict on learners' conceptual change about floating and sinking," *Research in Science & Technological Education,* vol. 31, no. 2, pp. 133-152, Jul 2013, doi: 10.1080/02635143.2013.811074.

[18] E. Linnenbrink and P. R. Pintrich, "Achievement Goals and Intentional Conceptual Change: Elizabeth Linnenbrink and Paul R. Pintrich," in *Intentional conceptual change*: Routledge, 2003, pp. 345-371.

[19] M. T. Chi, "Learning in a Non-Physical Science Domain: The Human Circulatory System," 1991.
[20] P. Kowalski and A. K. Taylor, "The effect of refuting misconceptions in the introductory psychology class," *Teaching of Psychology,* vol. 36, no. 3, pp. 153-159, 2009.
[21] X. Zhou, J. Di, and X. Tu, "Investigation of collapse of Florida International University (FIU) pedestrian bridge," *Engineering Structures,* vol. 200, p. 109733, 2019.
[22] M. Limón and L. Mason, *Reconsidering conceptual change: Issues in theory and practice*. Springer, 2002.
[23] L. Verschaffel and S. Vosniadou, *The conceptual change approach to mathematics learning and teaching*. 2004.
[24] G. J. Posner, K. A. Strike, P. W. Hewson, and W. A. Gertzog, "Accommodation of a scientific conception: Toward a theory of conceptual change," *Science education,* vol. 66, no. 2, pp. 211-227, 1982.
[25] C. Foster, "A slippery slope: Resolving cognitive conflict in mechanics," *Teaching Mathematics and its Applications: An International Journal of the IMA,* vol. 30, no. 4, pp. 216-221, 2011.
[26] K. A. Strike and G. J. Posner, "A revisionist theory of conceptual change," *Philosophy of science, cognitive psychology, and educational theory and practice,* vol. 176, 1992.
[27] P. R. Pintrich, R. W. Marx, and R. A. Boyle, "Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change," *Rev Educ Res,* vol. 63, no. 2, pp. 167-199, 1993.
[28] J. A. Dole and G. M. Sinatra, "Reconceptalizing change in the cognitive construction of knowledge," *Educ Psychol,* vol. 33, no. 2-3, pp. 109-128, 1998.
[29] O. O. Adesope, T. Lavin, T. Thompson, and C. Ungerleider, "A systematic review and meta-analysis of the cognitive correlates of bilingualism," *Rev Educ Res,* vol. 80, no. 2, pp. 207-245, 2010.
[30] A. Liberati *et al.*, "The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration," *Annals of internal medicine,* vol. 151, no. 4, pp. W-65-W-94, 2009.
[31] G. Taasoobshirazi and G. M. Sinatra, "A structural equation model of conceptual change in physics," *Journal of Research in Science Teaching,* vol. 48, no. 8, pp. 901-918, 2011.
[32] J. Ranellucci, K. R. Muis, M. Duffy, X. Wang, L. Sampasivam, and G. M. Franco, "To master or perform? Exploring relations between achievement goals and conceptual change learning," *British Journal of Educational Psychology,* vol. 83, no. 3, pp. 431-451, 2013.
[33] E. A. Linnenbrink and P. R. Pintrich, "The role of motivational beliefs in conceptual change," in *Reconsidering conceptual change: Issues in theory and practice*: Springer, 2002, pp. 115-135.
[34] C. L. Thomas and L. A. J. Kirby, "Situational interest helps correct misconceptions: An investigation of conceptual change in university students," *INSTRUCTIONAL SCIENCE,* vol. 48, no. 3, pp. 223-241, JUN 2020, doi: 10.1007/s11251-020-09509-2.
[35] G. Taasoobshirazi, B. Heddy, M. Bailey, and J. Farley, "A multivariate model of conceptual change," *Instructional Science,* vol. 44, no. 2, pp. 125-145, 2016.
[36] K. R. Muis *et al.*, "Main and moderator effects of refutation on task value, epistemic emotions, and learning strategies during conceptual change," *Contemp Educ Psychol,* vol. 55, pp. 155-165, 2018, doi: 10.1016/j.cedpsych.2018.10.001.
[37] S. H. Jones, M. L. Johnson, and B. D. Campbell, "Hot factors for a cold topic: Examining the role of task-value, attention allocation, and engagement on conceptual change," *Contemp Educ Psychol,* vol. 42, pp. 62-70, 2015, doi: 10.1016/j.cedpsych.2015.04.004.
[38] M. W. Grimes, "How Does Learning in Leadership Work? A Conceptual Change Perspective," *Journal of Leadership Education,* vol. 14, no. 4, pp. 26-45, 01/01/ 2015. [Online]. Available:

https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,shib&db=eric&AN=EJ1132031&site=ehost-live&scope=site&custid=uga1

http://www.journalofleadershiped.org/attachments/article/410/2015_0420.pdf.

[39] I. Thacker *et al.*, "Using Persuasive Refutation Texts to Prompt Attitudinal and Conceptual Change," *J Educ Psychol,* vol. 112, no. 6, pp. 1085-1099, 08/01/ 2020. [Online]. Available: https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,shib&db=eric&AN=EJ1263834&site=ehost-live&scope=site&custid=uga1

http://dx.doi.org/10.1037/edu0000434.

[40] S. P. Wu, B. Van Veen, and M. A. Rau, "How drawing prompts can increase cognitive engagement in an active learning engineering course," *J Eng Educ,* vol. 109, no. 4, pp. 723-742, 2020.

[41] J. L. De La Hoz, C. Vieira, and C. Arteta, "Self‐explanation activities in statics: A knowledge‐building activity to promote conceptual change," *J Eng Educ,* vol. 112, no. 3, pp. 741-768, 2023.