The Phenomenographic Analytical Framework in Science, Technology and Engineering Education Research

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Abstract: **Phenomenographic analytical paradigm helps to elicit qualitatively, variations of ways of understanding of interviewees through an in-depth data collection and analysis process. It helps to delineate the different ways people conceptualise, interpret and perceive a given phenomenon that appears intertwined with several other ones when investigated. Given that, there are embedded skills and practices that are integral, core and critical in the teaching and learning process in science, technology, engineering and mathematics discipline that do not carry equal glamour in policy declaration,curriculum implementation and other practices. Science, technology, and engineering teaching practices has multi-tasks intertwined together that require proper coordination and harnessing of all the tasks to enhance the holistic training of the graduates. In this article, particular attention is drawn to the application of phenomenographic methodology to qualitative research in science, technology, and engineering phenomena that students learn collectively and simultaneously in a cluster.**

Keywords: **Phenomenography, analytical methodology, qualitative research, higher education, teaching and learning, science, technology and engineering education**

I. INTRODUCTION: PHENOMENOGRAPHY DESCRIBED

Phenomenography is a field of inquiry that provides qualitative researchers with experiential descriptions of the phenomenon under study (Marton, 1986). According to Marton (1981), phenomenography was originally developed from an educational framework by Ference Marton and co-research group in the Department of Education, University of Gothenburg, Sweden. It was designed as research approach to answer certain questions about thinking and learning. The word "Phenomenography" was coined in 1979 but started appearing in publications two years later (ibid). Marton viewed it as a content-oriented and interpretive way of describing qualitatively different ways in which people perceive and understand their reality. The aim of developing this approach in research is to describe, analyse and understand experiences in qualitatively different ways in an empirical manner (Bowden, 2000; Marton, 1986). This is what differentiates phenomenography from phenomenology.

A phenomenological study basically describes the meaning for various participants of their lived experiences of a known phenomenon (Creswell, 2017). The focus is on describing what the participants have in common as they experience a phenomenon, it reduces individual experiences with a phenomenon to a description of the universal essence of it. Phenomenology differs from phenomenography in that it deals with first-order perspective, while phenomenography deals with second-order perspective of a phenomenon (Marton, 1981). The first-order perspective deals directly with what is experienced about a phenomenon and not how the phenomenon is experienced in varieties of ways by the participant (i.e. the learner) as is the case with the second-order perspective in phenomenography. In phenomenological investigation and analysis, the concern is the meaning that people give to the lived world and their everyday experience without dealing with the thought of that which is lived (Larsson &Holmstrom, 2007).

To explain further the meaning of a 'second-order perspective', Marton(1986) emphasised that phenomonography adopts an experiential perspective in which the interest is not to describe things as they are, but rather things are characterised by the process of perception and thought, by focusing on conceptions of specific reality and the contents of thoughts. In a phenomenographic approach, the different qualitative ways of people's understanding, conceptualisation, interpreting and perception of a given phenomenon under investigation are described in detail. The focus of such details is to produce two distinctive outcomes of the phenomenographic study, namely, the emerging categories of description and the outcome space of the study (Marton, 1981). The categories of description represent the different ways of experiencing, or being aware of the phenomenon under study. These are used to facilitate the understanding of concrete cases of the study based on the conceptions of a specific reality. The categories bring several individuals' conception of a phenomenon into reliable terms that sufficiently describe the object well. Marton (1981) further added that the categories denote forms of thought of the respondents, which are brought together in order to characterise the perceived world. The outcome space on the other hand describes the relationships and interactions between categories. The outcome space consists of a number of categories of description which depict the relationship between these categories, generally forming some type of hierarchical structure. It is the secondary outcome of research findings.

In this article, the different ways respondents represent the phenomenon under study in science, engineering and technology education programme which depicts the full range of possible ways of experiencing the phenomenon in the entire programme are considered. The responses collectively put together are the outcome space. The proven contribution of phenomenography to educational research, as seen in Alant (2001) and described by Marton and Booth (2013), makes it an ideal method for analysis in science, engineering and technology education programme. In science, engineering and technology education, the phenomenographic approach reveals the variation in the ways faculty members perceive and enact different phenomenon and the ways students experience the act and skill of learning each of the phenomenon. In exploring a research problem using phenomenographic framework, Marton and Booth (2013) advise that we consider two aspects in our analysis: the referential and the structural aspects of the ways of experiencing a phenomenon as referred to in figure 1.

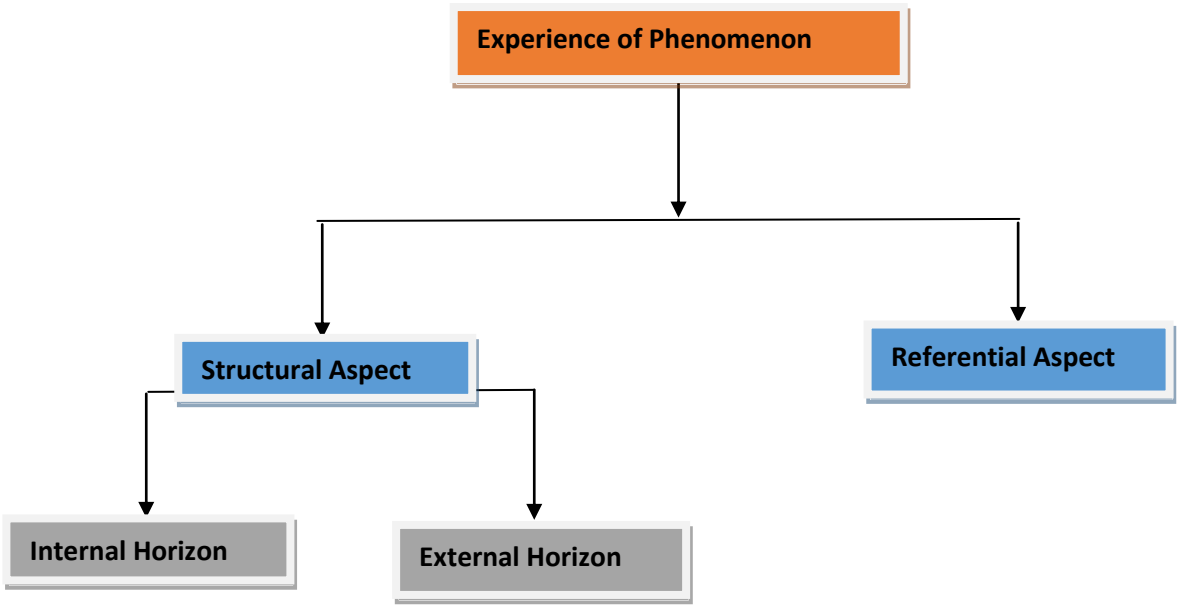

Figure 1: Component of phenomenographic experience (Adopted from Marton& Booth, 2013)

The referential aspect

The first aspect of the phenomenographic analytic framework, the referential aspect of experiencing a given phenomenon, is described as highlighting the direct object of the phenomenon, giving it a particular meaning based on the way it is experienced (Marton & Booth, 2013). This is the overall meaning attached to the phenomenon. In phenomenographic research, the referential aspect always answer the question "what" on the direct object of learning, giving the overall meaning and perception of a phenomenon (Khan, 2014). The "what" question addresses the particular meanings, the general understanding of the object of study? This aspect goes with research question on what is being perceived by relevant stakeholders.

The structural aspect

The structural aspect is defined as how people act towards something, practise something, how they go about to carry out something, how something is acted upon (Marton, Tsuiet al., 2004). It refers to the approach that is adopted in enacting a particular phenomenon in an educational programme. In the first place, it answers the "how" research question of the study, addressing how the phenomenon is being enacted in an educational programme of choice. The "why" research question is also unpacked by this aspect. Thus, the structural aspect of an experience is further divided into two aspects: the external structure and the internal structure of an object. These are referred to as external and internal horizons (Marton& Booth, 2013).

The internal horizon

The internal horizon of the way of experiencing a particular phenomenon is to discern the parts of the phenomenon of study, how the parts are interrelated as a whole (Marton& Booth, 2013). This is how different parts of the phenomenon are brought together, experienced and enacted. The internal horizon answers the "how" question. The internal horizon of the structural aspect directly deals with the different ways and strategies of enacting the phenomenon of study in an educational programme.

The external horizon

The external horizon of the way of experiencing a specific phenomenon is concerned with discerning the phenomenon (Marton & Booth, 2013; Khan, 2014). This is "what informs" the act, the intention for the action that is carried out in a particular way. It expresses the why of the internal horizon. Itanswers research question on "what informs" the how, and also informs the intention for the how action, in the participants' views. The external horizon of the structural aspect of experience has an indication of similarity to the referential aspect, but differs in analytical meaning and application (Marton & Booth, 2013). The two do not connote the same meaning. The external horizon of the structural aspect is applied at the level of inference to the research question "how", showing the intention for the how of the action, it focuses on the "what informs" the practice of a phenomenon. The referential aspect reflects the general understanding of the particular phenomenon under study. This is how the different parts of the phenomenon are brought together, experienced and enacted.

In the analytical procedures, three queries are to be answered using the phenomenographic approach. The three queries are the "what", the "how" and the "what informs" of the particular phenomenon in the science, engineering and technology programmes.

II. APPLYING PHENOMENOGRAPHY IN SCIENCE, TECHNOLOGY & ENGINEERING EDUCATION RESEARCH

Phenomenography provides qualitative researchers with experiential descriptions of the phenomenon under study (Marton, 1986). It is a qualitative research approach that aims at describing, analysing and understanding experiences in qualitatively different ways (Bowden, 2000; Marton, 1986). In this regard, it is the empirical study of the different ways in which people think of the world. Phenomenography seeks to describe the significant, or critical, features of the different ways individuals experience, conceptualize, realize and understand various aspects of phenomena in the world around them. This is the second-order view of the development of knowledge where a researcher is not making statements about a phenomenon directly, but rather about individual respondents' ideas of that phenomenon. In other words, "the interest is not to describe things as they are, instead, things are characterised the way they appear to people" (Marton, 1986).

The phenomenographic interview design

One aspect of planning a phenomenographic research that distinguishes it from other qualitative approaches is in the methodology that underpins its data collection approach (Collier-Reed & Ingerman, 2013). Data collection in phenomenographic interview represents the relationship between the participant and the phenomenon in the world as described by the participant (ibid.). Therefore, the uniqueness of the interview approach is found in that it facilitates the participant's reflection on their relationship with the phenomenon. Such reflection that will elicit relevant responses does not just manifest naturally, an appropriate method of data collection is required to enable it to happen. The interview questions should be so chosen and drafted to encourage the participants to express their qualitative understanding of the phenomenon under investigation. Bowden (2000) advised that the researcher may ask the participant to clarify what they have said, and ask them to explain their meaning further. It allows the participant to relate with the phenomenon freely as they express their conceptions about the world. The participant and the researcher also establish a shared definition of the phenomenon (Bowden, 2000).

There are three main research questions that naturally align with the three aspects of phenomenographic research structure, namely are,

i. The "What" question – referential aspect
ii. The "How" question – structural aspect (internal horizon)
iii. The "Why" question – structural aspect (external horizon)

The interview questions would be asked and addressed around these three questions on the phenomenon of investigation. For the questions to elicit relevant responses from participants, it has to be all open-ended or at most semi-structured. The first set of questions prompt different ways in which the participants perceive the phenomenon and the meaning they focus on when they are confronted with the phenomenon of study. The second set of questions elicit information about the approach, how the phenomenon is being approached; in other words, what strategies are employed based on their experience, conceptualisation and perception. The last set of questions provokes information on the intentions behind the enactment described in the second section. The interview questions should not seek 'correct' answers from the participants, but the participants' conceptualisation of the phenomenon at the time of the interview.

Phenomenographic analysis of interview data

The focus of data analysis in a phenomenographic approach is to identify and discern the subject's qualitatively different experiences or understanding in a limited number of categories (Khan, 2014). In order to achieve this, the first stage involves the process of becoming familiar with the transcripts as a whole. It comprises reading and re-reading each transcript several times in an attempt to reveal broad differences in pools of meaning. In the phenomenographic approach to data analysis, the transcripts are the focus of the analysis. The set of categories that are derived from the data as the results is not determined in advance, but emerges from the data, in relationship with the researcher (Åkerlind, 2012). The second stage involves separating chunks of text, or potentially relevant quotes from the transcript and then analysing these chunks for their meaning. This serves as a

means of thirdly, decontextualising the quotations from the individual respondents and thenfinally, using it to further identify common pools of meaning or categories, thus, revealing differences between the categories.

In analysing research data using the phenomenographic approach, the structural and the referential aspects of the studied phenomenon are significant and essential. When the participants narrate their story: what do they narrate, how do they experience what they narrate and what informs what they narrate about their experience of the phenomenon?

III. PHENOMENOGRAPHIC ANALYSIS PROCEDURES

The whole text are read carefully. The texts of individual participants are read again and divided into smaller sizes to mark out where the respondents gave answers to the interview questions. The three queries of "What", "How" and "Why" explained above are used to elicit the categories in individuals' responses.

In Fatokun's (2019) study on the engineering undergraduate's perception of troubleshooting, students' interview responsesreveal variation in their understanding. Eachchunk of quotes of therespondents elicitfirstly, the "what" focussing on what the narration was about the phenomenon in question (e.g. design problem solving, troubleshooting, debugging in software), secondly, the "how" which describes way of doing it (e.g. identifying problems in design, or structuring project completion time) and the 'why' – the intention, the explanation given for the action, (e.g. to highlight troubleshooting stages in design). Then these descriptions are grouped into categories based on similarities and differences observed to formulate the categories of description. These categories of description are then organized hierarchically to find an outcome space which become the theme of results that are useful for further discussion in the study. This process is done for all the answers given to the interview questions for each of the research questions of the study. While the description on the individual level helps clarify and refine the categories of description, it does not classify individuals belonging to any particular category. In other words, individual variation was not used in the description of the outcomes and themes that eventually emerged.

The phenomenographicanalysis process is also guided by emerging understandings of how the act and outcomes of learning may be described (Marton& Booth, 2013). The particular focus inherent in phenomenography which produce two distinctive outcomes for any phenomenographic study namely; the categories of description and an outcome space (the major themes that emerged as findings of the study) are further highlighted.

(i) Categories of description captures the critical dimensions of what the participants conceive as their conceptualisation of the phenomenon of study, and

(ii) An outcome space which describes the relationships and interactions between the categories.

Each category of description represents one 'conception' or way of experiencing or being aware of or constituting the phenomenon and the way of conceptualizing it in an educational programme. The categories of description are later synthesized into themes that represents the outcome space, the results of findings in the study. In order to arrive at the expected categories of description and outcome spaces for the study, the following processes of analysis could be followed for each stages of research questions.

IV. VALIDITY AND RELIABILITY IN PHENOMENOGRAPHIC APPROACH IN SCIENCE, TECHNOLOGY AND ENGINEERING EDUCATION RESEARCH

Phenomenographic research does not concern itself with reliability but explores credibility and validity. The main issue of credibility in a phenomenographic analytic approach is based on the relationship between the data obtained from interviews and the categories for describing the ways in which people experience a certain phenomenon (Sjostrom & Dahlgren, 2002). To ensure credibility in phenomenographic approach, data are carefully transcribed; the categories of descriptions carefully selected to describe the similarities and differences that emerged. Excerpts from the interviews should be provided to support the categories described. The excerpts should be relevant to the categories of description that emerged from the interview.

On credibility in phenomenographic research, Marton (1988, p. 148) argued that in case of phenomenographic analysis, the issue of replicability is not justified or even desirable. According to her, the categories of description could be referred to as constituting the "discovery" of the study. The categories of description provide the original finding of the study and the discoveries do not have to be replicable (Sjöström & Dahlgren, 2002). But once the categories have been found, it must be possible to reach a high degree of intersubjective agreement concerning their presence or absence, if other researchers are to be able to use them. Replicability is defined by Marton (1988) as introducing intersubjective agreement. This implies that another researcher can apply the proposed categories and classify the excerpts to determine the degree of concordance between the two outcomes. If the degree of concordance is acceptable, then the categories of description is replicable in that case, otherwise it is not.

In terms of validity, three types of validity checks highlighted in phenomenographic research by Booth (1992) are:

(i) content-related validity checks – the research has to be based on a comprehensive understanding of the subject content;

(ii) methodological validity checks – the phenomenographic approach should be infused into the study from the data collection stage, through the analysis to the presentation of the results;
(iii) communicative validity checks – the study should seek feedback from other populations represented by the interview sample and intended audience for the findings.

On content validity checks, the researcher should be well familiar with the phenomenon under study. With respect to methodology check, the phenomenographic approach should be involved in all the stages in the study. The research questions are crafted to reflect the three aspects constituted by phenomenographic methodology – the referential (the what? question), the structural (internal horizon – the how? question) and the structural (external horizon – the why? question). Data collectionand analysis is also characterized by the use of three queries of "what", "how" and "what informs", to interrogate, interpret and analyse the responses from the respondents.

According to Arkerlind (2012), phenomenographic research does not seek feedback from interviewees because it is regarded as inappropriate for phenomenographic validity checks. The reasons advanced for this standpoint is that the interpretations of findings and results are not based on individual participants' views, rather, it is made on a collective basis. The researcher could seek feedback from other respondents of similar characteristics to validate the results.

V. EXAMPLES OF PHENOMENOGRAPHIC RESEARCH

In this section, some examples of how phenomenography has been applied in science, technology and engineering education research demonstrates the uniqueness of the approach. Themulti-various ways of thinking held by individuals and groups on particular phenomenon are discussed.

InPhysics education

Sharma, Stewart and Prosser (2004) deliberately chose phenomenography approach due to their interest in identifying the variations in students' response in physics phenomenon. Two groups of students were investigated. The first group were investigated on their understandings of gravity in physics. The second group was on the first-year university students' awareness of physics. In the first group, students' responses in the in-depth phenomenographic interview conducted elicited three categories of description which include: a) existence or absence of gravity at the spaceship; b) freefall explanation; and c) utilisation of scales and normal force to explain the absence of a reading on the scales.In the second group, four distinct categorisations emerged about students' awareness of physics in university curriculum. Category 1 had little or no information about physics of motion; Category 2 had list like information; Category 3 linked physics ideas with concepts and Category 4 linked physics with communication or development of technology. Thus, the analysis elicit the various conceptualisations of physics' students exposed to same university syllabus and curriculum.The first study provides a methodology for how students understand and link concepts whereas, the second made a comparisons of students awareness of physics. The study allowed for different pattern of responses to emerge while participants are exposed to similar interview questions and their responses depicts the qualitative ways of understanding the phenomenon under study.

In Nursing education

Sjostro and Dahlgren (2002) in a review on "applying phenomenography in nursing research" presented two typical empirical research conducted on "understanding patients' experiences of their illness". In Hansson Scherman's (1994) study, how patients with asthma experienced their illness with particular regard to which strategies they developed in order to cope with their everyday life as chronically ill patients was the focus. Fourteen (14) different categories of description of how asthma patients relate to their illness emerged. These categories differ with respect to concept of illness, explanation of the illness, the course of illness and identity.Conclusively, Sjostro and Dahlgren (2002) argued that, these categories revealed strategies patients adopt to maintain their identity as heathy individuals.

Furthermore, the review revealed that,Fallsberg (1991) conducted a phenomenography study on patients suffering from hypertension, asthma or chronic pain, it was found that the three categories of descriptionabout patients' diseases emerged in qualitatively three different ways. In Category 1, patients with asthma were all very concerned about the occurrence of acute status asthmaticus. In Category 2, patients with hypertension were worried about the risk of stroke, which made them very compliant with medication. In Category 3, patients with pain had an experience of not being taken seriously by health care personnel. Sjostro and Dahlgren (2002) counselled further that phenomenography research possessed the potential to supply the discipline of nursing and nursing education with relevant knowledge about variations in how patients, nurses and students conceptualise phenomenon differently and how the phenomenon is experienced differently.

From an Anaesthesiologists' perspective

Larsson and Holmström (2007) conducteda phenomenographic study from anaesthesiologists' perspective to find out the answer to the question 'What is 'anaesthesiology?' or what do experienced anaesthesiologists perceive as anaesthesiology? In the study, 19 experienced anaesthesiologists were interviewed using a qualitative approach.The analysis of the interview responses revealed four different ways of understanding the anaesthesiologists's work. In summary, the four categories assigned to the respondents' interviews were: "firstly, seeing the patient as physiological object, monitoring and controlling her vital functions –this could be referred to as the professional artist;

secondly, seeing the patient as a person, guiding her safely through the operation: also referred to as the good Samaritan; thirdly, serving others in the hospital system, the patients, the doctors and nurses; this is referred to as the servant; and fourthly, organising and leading the operating theatre and team; simply referred to as the coordinator. These categories of description that emerged helped the researcher in expressing various ways of conceiving a phenomenon. Going by this study, the categories of description were analysed logically and hierarchically into outcome space by interacting the possible relationships between the various interpretations assigned to anaesthesiologist's work. For an instance, the anaesthesiologist with the understanding in the second category helped the patient to go through the operation and anaesthesia safely and successfully. To achieve this function, the anaesthesiologist must control the patient's vital organs - the first category, and coordinate the operation team - the fourth category.

In Engineering education

Pan, Strobel and Cardella (2014) conducted a phenomenographic research on engineering students' experiences of workplace problem solving. The researchers realised that it is unclear how engineering students, who will become professionals in the workplace after graduation, will experience real world engineering problem solving. It the study, 22 engineering co-op students were interviewed. Phenomenographic analytical approach was conducted on the interview transcripts to elicit the variation in students' experiences. The analysed results categorised workplace problem solving to six different ways namely; "workplace problem solving following orders and executing the plan, implementing customers' ideas and satisfying customer needs, using mathematical and technical knowledge and skills to solve technical problems, consulting different people and collecting their inputs, using multiple resources to draw conclusions and make decisions,and exploration and freedom".The second stage of phenomenographic analysis revealed two-dimensional outcome space. These were the horizontal and vertical axis of interaction. Whereas, the horizontal axis represents an increased involvement in problem definition and formulation, the vertical axis represents involvement in solution generation and selection. The results of the study have implications in engineering education and for engineering practice. For instance, the outcome depicts a path for engineering educators to design different learning experiences in the classroom to better prepare students with the knowledge and skills required in the workplace. On the part of engineering practice, it creates an awareness of the factthat there are different types of problems in the engineering workplace and a variety of ways engineers experience problem solving might help them become more reflective in their engineering practice and make better decisions when approaching problems".

Phenomenography research in technology

Bruce, Buckingham, Hynd, McMahon, Roggenkamp and Stoodley (2004) in a phenomenographic research investigated the act of learning to program by university students. In the study, 20 first-year university students were interviewed using semi-structured interview questions. The phenomenography research approach revealed variations in how the act of learning to program may be constituted among first-year university students. The analysis indicated five different ways students go about learning to program: by (a) Following – where learning to program is experienced as 'getting through' the unit, (b) Coding – where learning to program is experienced as learning to code, (c) Understanding and integrating – where learning to program is experienced as learning to write a program through understanding and integrating concepts, (d) Problem solving – where learning to program is experienced as learning to do what it takes to solve a problem, and (e) Participating or enculturation –where learning to program is experienced as discovering what it means to become a programmer.The outcome space reveals the widening awareness associated with the different categories of description. The first category depicts the learning institution, the second depicts the programming language, the third deals with programs and programming, the fourth focused on problem solving while the last refers to the programming community. The outcome space and categories of description provides a platform for application to teaching practice. The interaction between the differences and similarities among the groups could form thebasis forteachers to design learning experiences which could encourage change.

VI. DISCUSSION

Educational benefits of phenomenograhic research approach in science, technology and engineering education

The results of phenomenographic analytical approach can be of great benefit to researchers in science, technology and engineering education programmes. It would help to diversify the analytical approach to educational research and improve the quality of results that emerge from qualitative research, particularly where several phenomena are intertwined and learned simultaneously such as noticed in problem solving(Pan, Strobel & Cardella, 2014). Problem solving is broad and consists of varieties of learning experiences which ought to be fully explored in science, technology and engineering education. Previous studies have revealed that policy makers, teachers, technologists and students differ in their conceptualisation, perception and understanding of existing phenomena in teaching and learning experiences (Larsson &Holmström,2007; Sjostro & Dahlgren, 2002; Marton, 1986). Phenomenographic analytical approach would help to interrogate, interpret and analyse the responses from the respondents to unfold the availability or non-availability of certain phenomenon. Through the phenomenographic analytical procedures, categories of description reveals the different ways in which the participants are aware of the

phenomenon of study in science, technology and engineering education programmes. The outcome space that emerged from the categories of description from participants' narratives are synthesized into themes, providing a better understanding of the reality of the phenomenon studied.

This article argues that phenomenography research methodology possesses relative strength in investigating qualitatively,phenomenon in science, technology and engineeringeducation. In these fields, there are various ways students and staff members experience and perceive the world around them.The phenomenographic approach unfolds this myth in the pedagogy of teaching and learning several interrelated phenomenon in these fields.

Implications

The phenomenographic methodology simply supply the disciplines of science, mathematics and technology education with knowledge about variations in how students and staff think about the world around them.

The phenomenographic analytical approach especially, the structural and referential aspect, elicit the paradigmof conducting in-depth qualitative inquiry.

The categories of description and the outcome space that emerged after analysis of interview data describes people'svarious ways of reasoning which can be fed into teaching and learning for a better and fruitful educational output in the disciplines of science, mathematics and technology education.

VI. CONCLUSIONS

Phenomenography has been recognized as an innovative qualitative research paradigm within higher education research. Researchers that are interested in specific student learning experiences and in-depth understanding of variations in teaching and learning approaches in science, technology and engineering education might consider adopting varied approaches to elicit concrete results which can be discovered in phenomenography.

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