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Preconceptions of Bachelor of Science Education (Honours) Degree in Physics Students about Compton Effect

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ABSTRACT

Physics education research has established that students' preconceptions play a dominant role in teaching and learning of physics from elementary levels up to University. College students have been known to ignore information presented to them in lectures when it is inconsistent with their prior convictions some which are misconceptions. Research studies show that students' preconceptions must be identified first before new concepts and explanations are learnt. This study aims to determine preconceptions of Bachelor of Science Education (Honours) Degree in Physics Students around the concept of Compton scattering particularly as explained using the concept of light. This qualitative study was conducted with 40 Bachelor of Science Education (Honours) degrees in Physics students at a state university in Zimbabwe. Data were analyzed descriptively. The students' preconceptions that emerged were categorized as scientific concepts, misconceptions, lack of concept and error. The results showed that average of 21.8% of students had scientific concepts, 45.76% of students experience misconceptions, 18.54% of students experience lack of concepts and 14.23% of the students experience errors. This study revealed that not all preconceptions held by students are misconceptions as the results show a mixture of correct ant incorrect conceptions about Compton Effect. The study recommends that it is important to identify students' preconception on Compton Effect to enable instructors to design effective instructional interventions and strategies for reinforcement of correct preconceptions and conceptual change for the wrong preconceived ideas.

Introduction

Every student enters physics classes with many preconceived ideas or a well-established system of beliefs and opinions about how the physical world works derived from years of personal experiences (Fadaei & Mora, 2015; Wahyuni, Rustaman, & Rusdiana, 2019). Therefore teaching of physics does not start on a virgin territory. Preconceptions are one of the defining factors to physics teaching in schools (Hewson & Hewson, 1983). Many studies in Modern Physics have concluded that, some learning difficulties experienced by learners are sometimes caused by preconceptions (Suma, Sadia, Pujani, & Rapi, 2019). Although many studies about preconceptions have been conducted, there seem to be no clear definition of preconception (Moon, Carpenter, Hansen, Bushong, & Bianchini, 2021). Among the proposed definitions are also some that are quite profound. For example, Eryilmaz (2002) posits that preconception refers to the conception that has been formed before formal teaching of a concept in school. Preconception is knowledge that students have before learning starts (Edinyang, 2006). Various names have been given to preconception such as; prior knowledge (Suma et al., 2019)

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children's science (Ausubel, Novak, & Hanesian, 1968); alternative conception (Petersson, 2002) and misconception (Clement, Brown, & Zeitsman, 1989). In this article the terms preconception and prior knowledge are used interchangeably.

Student's preconception can either conform or conflict with scientific conceptions (Suma et al., 2019). Students' preconceptions that conform to scientific conception strongly support learning of students. In most cases preconceptions are quite different from scientific notions (Zhou, 2008). There remains a lack of agreement in the field of science education as to whether student's preconceptions that conflict with scientific views (misconceptions) ought to be considered obstacles or resources in teaching and learning of physics(Moon et al., 2021). Swati, Patil Rajendra, Chavan, and Khandagale (2019) and Winne (2021) argue that preconceptions that conflict to scientific concepts(misconceptions) can be a barrier to students' learning. Preconceptions that do not confirm to scientific concepts are among the number one factors leading to students failure when studying physics (Li, Li, & Wang, 2021; Özkan & Selçuk, 2013). Preconceptions directly influence students' future learning and understanding of concepts as they become integrated into the students' cognitive structures (Demirci, 2005; Kambouri, 2015; Winne, 2021). Learners construct their knowledge and concepts in the direction of their individual abilities and experiences (Kumi-Manu, 2021). Preconception can influence how students perceive, assimilate, organized, and make connection of new information (Svinicki, 1993; Swati et al., 2019). Preconceptions have a significant impact on learning and critical-thinking ability of students (Byfield, East, & Conway, 2019). When the preconceptions are misconceptions, they hamper the learning of individuals as students find it difficult to integrate new information within their cognitive structures and may also lead to their loss of interest in the subject (Priyadi, 2021; Winne, 2021). Pre-conceptions which do not conform with scientific knowledge may lead to confusion or eventually loss of confidence among the students if they are not properly handled (Swati et al., 2019).

The challenge for educators is to recognize and manage these preconceptions and all educational levels to ensure an effective learning experience (Byfield et al., 2019). Many studies have been done to identify preconceptions of students on various physics topics (Hall, 1996; Zhou, 2008). This study focused on identification of preconceptions among Bachelor of Science Education (Honours) degrees in Physics students at a state university in Zimbabwe about Compton Effect. Ausubel et al. (1968) contends that the most important single factor influencing learning is what the learner already knows. Learning involves, among other processes the altering and restructuring of the preconceived ideas, explanations, and conceptions of science that learners possess (Kyle & Shymansky, 1989). In a typical sequence of instructional events using the Constructivist epistemology instructors have to determine students' preconceptions using interviews, diagnostic tests or other approaches before cataloguing the preconceptions (Igwebuike, 2013). The identification of preconceptions is one of the important pre-stage factors that shape the views and behaviors of students and educators in respect of how each learn or teach (Biggs, 2003). Meaningful learning takes place when correct information in the preconceptions is identified and indorsed and also when incorrect information is identified, revised, replaced and this is called the "Conceptual Change Process" (Li et al., 2021). Preconceptions occur among students because each student has different interactions within physics content, physical and social environments (Tekkaya & Balcı, 2003). Factors that contribute to the development and nature of preconceptions include interaction with of learners with teachers, parents, teaching materials or literature, context and personal experience (Giuseppe & Fraser, 2012).

Therefore, to teach physics effectively preconceptions should be identified and associated misconceptions should be spotted and overcome (Kumi-Manu, 2021; Özkan & Selçuk, 2013). Because of the impact preconceptions have on learning, teachers and researchers should have a good knowledge of learners' existing preconceptions about the concepts targeted by instruction before the actual instruction begins (Coştu, Ayas, & Niaz, 2010). It is expected that knowing preconceptions, among physics students would make it easier for educators to find ways of accommodating scientifically correct conceptions and also minimizing misconceptions when teaching the concepts (Giuseppe & Fraser, 2012). Students' preconceptions inclusive of misconceptions should be taken into consideration in the development of science curricula and instructional materials (Demircioglu, Ayas, & Demircioglu, 2005). Detecting the preconceptions including their misconceptions in earlier stages of learning may help to arouse interest and boost the confidence in learners in the subject (Swati et al., 2019). Lecturers would design learning experiences that build on that pre-existing knowledge (Cabrera, 2019). Generally new information has to filter through the preconceptions (Moon et al., 2021).

During teaching and learning processes preconception structures particularly those associated with misconceptions among students have to be fundamentally restructured to allow them to acquire science concepts and induce perspective transformation (Duit & Treagust, 2003; Winne, 2021). Instructors need to re-shape students' misconceptions into coherent concepts (Pines & West, 1986). The studies on preconceptions of students may improve understanding of the reasons behind the difficulties that they experience in learning physics concepts (Chrzanowski, Grajkowski, Żuchowski, Spalik, & Ostrowska, 2018). Tippett (2010) stated that preconceptions may be considered as essential and unavoidable features of learning. The lecturers would use the identified preconceptions to plan and design the right strategy to adopt correct conceptions and reconstruct the misconceptions to become scientific concepts.

Compton Effect (Compton scattering) is one of the concept in modern physics that is explained using the concept of light. Light is also one of the concepts in physics learners struggle to understand (Heckenson, 2018). Compton Effect is the scattering of a photon by an electron (Young, 2012). Energy and momentum are conserved in such an event. The scattered photon has less energy (longer wavelength) than the incident photon. Compton Effect is one of the ways in which electromagnetic radiation interacts with matter as made of particles. Compton Effect also confirms the reality of photons. It constitutes evidence in support of the quantum theory of radiation. It is one of the cornerstones of quantum mechanics, which accounts for both wave and particle properties of radiation as well as of matter. The paradox is described as wave-particle duality. Compton Effect as a phenomenon contributed to the emergence of the modern quantum theory (Young, 2012).

The study is based on Constructivist theory derived from the Cognitive learning theories (CLT). According to CLT, students build new knowledge based on their preconception or prior knowledge. Constructivism is a major theoretical perspective informing science teaching (Taber, 2011). Constructivist view of learning emphasizes the view that 'knowledge cannot be transferred ready-made directly from one knower to another, but is actively built up by the learner (Denbel, 2014; Pande & Bharathi, 2020). The theory emphasizes the importance of preconception in learning as it argues that students learn through the process of reconstructing existing knowledge (Suprapto, 2020; Svinicki, 1993). The main idea is that Students' learning is centered on building new knowledge upon the foundation of preconceptions acquired from both formal and informal settings. Knowledge is constructed by building new understandings on preconceptions which may be correct or incorrect (misconceptions). When the preconceptions are incorrect (misconceptions), the impact on learning is detrimental. Generally, developing students' understanding in physics needs to start from their existing concepts. Preconceptions serve as a platform from which students interpret their world (Zhou, 2008).

If learning is based on prior knowledge, then instructors must know the preconceptions inclusive of misconceptions so that they can provide learning environments for development of concepts from learners' current understandings, while accommodating new experiences (Kambouri, 2015), hence the undertaking of this study. Gurel, Eryilmaz, and McDermott (2015) argue that diagnosis of preconceptions of students in a valid and reliable way have great importance in science education research. Since preconceptions particularly misconceptions are very resistant to change and sometimes problematic for further scientific knowledge, it is crucial to determine them correctly (Gurel et al., 2015). In order to correctly teach a concept, the prior information inclusive of misconceptions of students, if any, should be identified and the teaching process should be planned with these in consideration (Kumi-Manu, 2021). Identification of preconceptions of learners enables lecturers to present richer learning experiences and create worthwhile opportunities that enhances learning (Denbel, 2014).

Methods

Participants

The study was conducted with 40 Bachelor of Science Education (Honours) degree in Physics (BScEdHP) part 1.2 students at a state university in Zimbabwe. Ethical clearance was sought from the university before getting informed written consent from the students to participate in the study and also to have the findings of the research published. Although the participants had not previously received formal teaching on Compton Effect at honours degree level, they had learnt about the nature of light and its interaction with matter particularly Wave particle duality, photoelectric effect and even Compton Effect in their advanced level physics syllabus, Diploma in Science Education program(physics) and Physics undergraduate program. Thus, the students' responses in the study could be interpreted as their preconceptions about Compton Effect before formal instruction of the concept at honours degree level.

Instruments

Data were collected using Three Tier Compton Effect Diagnostic Test [TTCEDT]. Diagnostic tests are deemed suitable for exposing students' conceptions about a scientific concept(Zhou, 2008). A three-tier diagnostic instrument is a multi-level assessment model used in knowing the weakness and mistakes of students in understanding a concept (Swati et al., 2019). This concept was adopted from tests that were proposed by Hrepic, 2004; Tamir, 1989 and Swati et al. (2019). Swati et al. (2019) describes Three Tier Diagnostic tests as diagnostic instrument where in the first tier includes multiple choice content questions with three choices. The second tier consists of multiple-choice set of three possible reasons for the answers to the first tier. The reasons consisted of the designated correct answer, together with common students' misconceptions identified from literature. Students were required to justify their section of answer in multiple-choice items in the form of short answers. The third tier is used assessing students' confidence about the answers they would have given in the first two tiers. The TTCEDT had 20 items. The test identified several Compton Effect sub concepts as follows: Compton Effect versus Photoelectric effect, Cause of scattering, Energy of a photon, momentum of a photon, Wavelength of a photon, Nature of the interaction between photon and electron, Nature of photons. The number of TTCEDT Test items related to each sub concept above is shown in Table 1.

Table 1
Three-Tier Compton Effect Diagnostic Test items related to each sub-concept of Compton Effect

Compton effect concept	Item Number
Compton Effect versus Photoelectric effect	1, 2, 3
Cause of scattering	4,5, 6
Energy of a photon,	7, 8,9
momentum of a photon,	10,11,12
Interaction between photon and electron	13.14, 15
Wavelength of a photon,	16, 17
Nature of photons	18, 19, 20

Data Collection

This was done in two phases. Phase one involved piloting the diagnostic test (TTCEDT) with 15 students. Students who took part in pilot study were excluded from the actual study to avoid contamination of data. After the pilot study some minor clarifications were made in TTCEDT items prior to the actual administration of the test. The reliability coefficient of the test was assessed by computing Cronbach Alpha estimates of internal consistency which was found to be 0.58. The reliability of the test though modest was considered acceptable, given the purpose of the study. Cronbach Alpha estimate is a reliability coefficient that provides a method of measuring internal consistency of tests(Cho, 2016). The test was validated by a panel of five qualified university physics lectures. Phase two involved administration of the diagnostic test [TTCEDT] to 40 BScEdHP part 1.2 students.

Data Analysis

The data on students' preconceptions were analyzed descriptively. Descriptive Analysis offers high degree of objectivity and neutrality of the researcher. The students' preconceptions of Compton Effect concepts were classified into four categories: Scientific Concept (SC); Misconception (M), Lack of Concept (LC), and Error (Er). The categorization was based on the combination of the student's responses in the first, second, and third tiers of TTCEDT as shown in Table 2.

Table 2
Categorization of the students' responses

1st Tier	2st Tier	3st Tier	Students' Preconception Category
Right	Right	Sure	SC
Right	Right	Not Sure	LC
Wrong	Right	Not Sure	LC
Right	Wrong	Not Sure	LC
Wrong	Wrong	Not Sure	LC
Wrong	Right	Right	ER
Right	Wrong	Sure	M
Wrong	Wrong	Sure	M

Result and Discussions

BScEdHP part 1.2 Student's Preconception Categories about Compton Effect

Analysis of data indicates that before starting formal instruction students had preconceptions on scientific concepts. In this particular study BScEdHP part 1.2 students had preconceptions about Compton Effect. This study revealed that not all preconceptions held by students are misconceptions as the results show a mixture of correct and incorrect conceptions about Compton Effect. This agrees with Clement, Brown, and Zietsman (1989) who note that not all preconceptions about a scientific concept held by students are misconceptions. In this study most of the preconceptions held by students were misconceptions which may have been a result of exposure to related and similar concepts in their previous learning experiences. Students revealed a variety of preconceptions some of which were common among them. Analysis of student's responds to TTCEDT indicates that their preconceptions on Compton Effect could be classified into: SC, M, LC, and Er. The percentage of the students' experience of SC, M, LC, and Er are shown in Table 3.

Table 3
The percentage of the BScEdHP students' experience of Scientific Concept (SC); Misconception, Lack of Concept (LC), and Error (Er).

Sub Concept	SC (%)	M (%)	LK (%)	ER (%)
Compton Effect versus Photoelectric effect	26.3	35.22	12.02	26.36
Causes of scattering	24.89	26.14	27.23	11.67
Energy of a photon	24.63	38.98	24.64	11.75
Momentum of a photon	10.60	52,67	25.3	11.43
Nature of the interaction between photon and electron	14.72	54.22	26.06	5.00
Wavelength of a photon	16.07	50.22	8.72	24.99
Nature of photons	33.18	52.80	5,82	8.20
Average	21.48	45.76	18.54	14.23

Table 3 shows that highest percentage of students who experience the scientific concepts category was on the Nature of Photons, and the lowest on the Momentum of a photon. The highest percentage of students who experience a misconception was on the Nature of interaction between photon and electron, and the lowest is on Compton Effect versus photoelectric effect. Under the category lack of concept, the highest percentage of students who were experience it was on the causes of scattering and the lowest is on nature of photons. The highest percentage of students who experience an error was on Photoelectric effect versus Compton Effect and the lowest was on the nature of interaction between a photon and an electron. The highest average percentage of students is in the misconception category (45.76%) followed by Scientific Concept (21.48%). This indicates that the majority of the preconceptions held by the students are misconceptions. Very few preconceptions are errors (14.23%). Preconception categorized into lack of concept constituted 18.54%. The analysis indicates that before students are engaged in formal instruction they have mixed or partial understandings in the targeted concept in which they hold simultaneously correct and incorrect ideas about that particular scientific concept

Variety of Preconceptions about Compton Effect identified among the BScEdHP part 1.2 students

The preconceptions revealed in the students' responses to the TTEDT on Compton Effect concepts included both correct and wrong scientific conceptions. The preconceptions of BScEdHP part 1.2 students identified through the TTEDT include the following:

1. The scattered photon has the same energy as the incident photon (wrong).
2. The scattered photon has a shorter wavelength than the incident photon (wrong).
3. The scattered photon has less energy (or longer wavelength) than the incident photon (correct).
4. Photon has Zero mass.
5. There is a time lag between the appearance of the outgoing photon and the recoil electron (wrong).
6. Outgoing photon and recoil electron appear simultaneously (correct).
7. In addition to carrying energy a photon carries a momentum and scatter like particles (correct).
8. The frequency or wavelength of the scattered radiation should depend on the length of time the electron was exposed to the incident radiation as well as on the intensity of the incident radiation (wrong).
9. Wavelength shift of X-rays scattered at a given angle is absolutely independent of the intensity of radiation and the length of exposure and depends on the scattering angle (correct).
10. The increase in wavelength does not depend on the nature of the scatter (correct).
11. Recoiling electron do not absorb energy from the incident photon (wrong).
12. The recoiling electron absorbs part of the incident photon and thus increases the frequency of the scattered photon (wrong).
13. The recoiling electron absorbs part of the energy of the incident photon resulting in less energy among the scattered photons and lower frequency (correct).
14. Recoiling electron releases energy to the scattered photon thereby increasing it was.

15. The photon–electron collision in the Compton effect is necessarily elastic (Correct).
16. Scattered radiation is a result of re-radiation from electrons that vibrate in unison with the electromagnetic field of the x-rays (incident photons) and emit radiation with the same frequency (Classical theory by Thomson) (correct classical explanation).
17. Radiation was produced by the collision between photons and electrons (correct).
18. In Compton' effect photons are recoiled (wrong).
19. There is partial absorption of energy of the photon by an electron (correct).
20. Compton effect is the same as photoelectric effect (wrong)

The preconceptions shown are very important material for selecting teaching strategies, especially conceptual changes strategies. The choice of teaching strategies is very important because mere classroom instruction in a topical area guarantees neither an understanding of the topic nor reduction in misconceptions (Arthurs, Elwonger, & Kowalski, 2021). The list of preconceptions can be longer with a different group of students.

Conclusions

The study focused on the preconceptions about Compton Effect among the BScEdHP part 1.2 students. The study was conducted after the realization that in order to effectively teach concepts in physics, the prior information inclusive of misconceptions held by students, if any, should be identified and the teaching process should be planned with this in consideration. Results indicate that before starting formal instruction students have preconceptions which can be correct or wrong on scientific concepts. There were four categories of student preconceptions, namely: scientific concept, misconceptions, lack of concepts, and errors. Most of students experience Misconceptions and only a small percentage had errors in the concepts. This study revealed that not all preconceptions held by students are misconceptions as the results show a mixture of correct ant incorrect conceptions about Compton Effect.

It is suggested that lecturers should identify students' preconceptions about the Concepts on Compton Effect before taking a formal teaching. Students' preconception can be used when designing the right strategy to reconstruct the student's preconceptions to become scientific concept. Future researches should look at how the preconceptions can be managed and integrated in instructional designs to promote conceptual understanding as well as conceptual change.

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