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The Place of Critical Thinking in Physics Instruction

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Abstract: *The teaching of critical thinking is paramount in physics instruction, it is achieved through acquisition of critical thinking skills by learners. Consequently, teachers of physics ought to employ instructional strategies that foster the acquisition of the skills. This article explores an array of these strategies in detail, it also presents the history and nature of critical thinking, the role of critical thinking in science instruction and the challenges teachers of physics face in teaching critical thinking skills.*

Keywords: *Challenges, Critical thinking, Critical thinking Skills, Instructional strategies, Physics instruction*

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1. Introduction

The earliest records of critical thinking date back to the teachings of Socrates (470–399 BC), as recorded by Plato, his student. Socrates established the importance of deep questioning and probing profoundly before accepting ideas as worthy of belief. He also established the importance of examining reasons & assumptions, finding out evidence, analyzing basic concepts and projection of possible implications of what is said and done. He was the founder of Socratic questioning, a questioning strategy in use up to date. Plato carried on with the Socrates tradition of critical thinking. Aristotle and other subsequent Greek philosophers refined Socrates teachings through use of systematic thinking and questioning to ascertain the nature of reality beyond the face value. John Dewey often considered as the father of modern-day critical thinking, explained it as an active, persistent and careful consideration of a belief or supposed form of knowledge in light of the grounds that support it and the further conclusions to which it tends (Dewey 1933). Dewey recognized that a curriculum aimed at building critical thinking skills would benefit the individual learner and the entire society. As such, the school system should emphasize on teaching critical thinking skills.

2. Nature of Critical Thinking

The nature of critical thinking can be explained from varied perspectives. Glaser (1941), explained critical thinking, as involving three elements: an attitude of disposition to consider in a thoughtful way the problems at hand, the methods of logical inquiry and the skills of applying the methods. Paul and Elder (2010) explained critical thinking as a mode of thinking about any subject, content or problem, whereby the thinker improves the quality of thinking through skillful handling of inherent structures of thought by imposing intellectual standards. From this perspective, critical thinking is seen to involve logical thought, an understanding of concepts and an ability to incorporate broader intellectual criteria. For instance, accuracy, credibility, relevance, precision, depth & breadth, fairness, significance etc.

Tiruneh et al (2016) explained that, though the development of critical thinking is a major goal of science education, adequate emphasis has not been given to its measurement in specific science domains, like physics.

They further pointed out that critical thinking involves the ability to identify relationships, analyze probabilities, synthesize, solve complex problems, draw inferences and make logical decisions. Likewise, Shaughnessy et al (2014), identified analysis, synthesis, evaluation and the ability to interpret & infer as critical thinking skills paramount in laboratory experiments. Willingham (2007) explained critical thinking in layman's terms as consisting of seeing both sides of an issue and demanding that claims be backed by evidence. He further noted that, there are specific types of CT characteristic of different subject matter. For instance, critical thinking skills in science will result in "thinking like a scientist", in history it will result in "thinking like an historian," amongst others.

Wood (2002) noted that critical thinking is the process of using reasoning to discern what is true, and what is false. It involves being logical, able to separate facts from opinions, open mindedness, and self-regulation. Wood's explanation brings out the multidimensionality of critical thinking, comprising of varied thinking skills dependent on each other for a common goal, in this context critical thinking is seen as a system of thoughts. Besides this, philosophy course of Berry College (PHI 150: 2007) explained that critical thinking begins with asking questions. For instance, if a teacher gives out an assignment, a good question to ask is, "how best can the problem be solved?" More often than not, learners do not ask this question, instead they try solving the problem by any method that spring into their minds. In the philosophy course, it is further observed that, critical thinking is different from just engaging in a mental exercise. First, it involves asking questions that go into the heart of the matter and secondly, trying to answer the questions through well-reasoned out judgment.

Ennis (2015) explained critical thinking as an intellectually disciplined process of actively & skillfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information gathered from observations, experiences, reflections or reasoning as a guide to action or belief. From the aforementioned explanations, critical thinking is seen as requiring lots of brain function and attention, therefore when incorporated in physics instruction it plays a considerable role in learners' cognitive development. Grieve (2013) explained critical thinking as a reflective and analytical style of thinking, with its basis in logic, rationality, and synthesis. It means delving deeper and asking questions like, why is that so? Where is the evidence? How good is that evidence? Is this a good argument? Is it biased? Is it verifiable? What are the alternative explanations? From this it can be deduced that, critical thinking is more than mere description, but delves into the realms of scientific inference and reasoning. Critical thinking begins with asking questions about a problem and ways to address it. Examples of questions asked include, how can it be solved? Are there alternative ways of solving it? What is the best way to begin? Is all the information required for solving available? What is the rationale behind the problem? Can it be solved? Does it even make sense? From this perspective it is evident that before embarking on problem solving, there has to be deep thought about what is at hand. Consequently, it is paramount to teach critical thinking skills in physics instruction to boost learners' problem-solving capabilities.

3. Role of Critical Thinking in Science Instruction

Luiz, (2017) noted that, science is an active process, a human activity where critical thinking is crucial and play a central role in knowledge generation. He identified the following science processes as being dependent on sound critical thinking:

i. Identification and defining a scientific problem
ii. Problem solving
iii. Critique and argumentation
iv. Rigorous testing and evaluation
v. Rejecting/accepting hypothesis
vi. Conclusions, clarification of meaning and decision making.

Norris (2018) argued that critical thinking aids learners understand the concepts and content of an area of study more clearly and effectively. She outlined intervening measures in cultivation of learner's critical thinking skills, as follows:

i. Establish what it takes to understand the subject matter at hand.
ii. Determine learner's own learning level and initial understanding of the subject matter
iii. Establish the thought processes necessary to understand the concepts and subject matter.
iv. Test one's newly acquired understanding of the subject matter.
v. Formulate questions that stimulate essential thinking, necessary for application of new knowledge.
vi. Expand one's ability in learning through the thinking process.

4. The Teaching of Critical Thinking Skills in Physics Instruction

Larsson (2019) noted that, educationist have had serious problems in proposing well-grounded ways of teaching critical thinking and that, many societies around the globe see enhancing learners critical thinking skills as one of the

most important learning goals in the school system. However, Behar-Horenstein, & Niu (2011) as cited in Larsson (2019) noted that, systematic reviews of research have concluded time and time again that there have been few substantial gains. Thus, the teaching of critical thinking skills in educational settings is still poor. Larsson's ultimate point of concern is that imparting learners with critical thinking skills is a global problem across disciplines. Swift (2017) in an article "critical thinking - attained through physics" noted that, science is about experimentation, creativity and even play, and that, the greatest breakthroughs have come from those who pushed beyond the known limits to ask why, how, and ultimately what if. Furthermore, she observed that, "if this is how the best science is done, then why don't we start giving students autonomy to explore and create?" Swift implies that, science learners are majorly in a comfort zone, within the "known limits," at the same time not given autonomy for exploration and creativity, in any case this autonomy will boost their critical thinking skills. Grieve (2013), observed that, for many scientists critical thinking becomes seemingly intuitive, but like any skill set, it needs to be taught and cultivated. She further noted that, "what does this mean for educators trying to incorporate critical thinking skills within their curricula?" From the question she suggested that theoretical elements of critical thinking should be taught.

The Association of American Colleges and Universities (AAC & U: 2005) noted that, the teaching of critical thinking skills in science lack comprehensive science curricula focusing on student acquisition of critical thinking skills. It further observed that, the most recent efforts to address the problem were in contexts of teaching critical thinking skills separately from subject matter domains. However, the approach became less dominant due to implementation challenges. Consequently, empirical attempts to develop learner's critical thinking skills shifted towards embedding the teaching of critical thinking skills within subject matter instruction. For instance, the teaching of physics content going hand in hand with the teaching of relevant critical thinking skills in physics lessons.

Basweti, et al (2019) explained that progressive research recognized the importance of teaching thinking skills through appropriate methodology as key to developing learners' problem-solving ability. Moreover, Okere (2006) in Basweti et al (2019) noted that, lack of expertise in physics has often been attributed to inadequate development of learner's critical thinking skills. To achieve optimal teaching of critical thinking skills, the choice of instructional strategies is paramount. Saputra and Aziz (2014) explained instructional strategies as thoughtful planning to instruction, encompassing a combination of different instructional methods and classroom activities purposed to create a conducive learning environment. They outlined the following as examples of instructional strategies: brain storming, demonstrations, case-based discussion groups and independent study. Similarly, Ayua (2017) explained an instructional strategy as an educational technique, method or plan of classroom actions intended to achieve a specific instructional goal. Other examples of instructional strategies are: project based learning, blended learning, inquiry based learning, laboratory experiments, problem based learning, cooperative learning, flipped classrooms, active learning and others.

Foster and Lemus (2015) indicated that, inquiry-based activities helped in improving learners' science skills by promoting awareness regarding to the role of creativity and critical thinking in scientific inquiry. Ranggi et al (2021) revealed that there is a strong positive effect of problem-based learning on critical thinking skills. Makmur et al (2019) noted that, guided inquiry with scaffolding strategy based on lesson study can improve critical thinking skills. Maknun (2020) observed that the implementation of guided inquiry learning can significantly improve the understanding of static fluid concepts and critical thinking skills of vocational high school students compared to conventional learning. This was because it provided the opportunity for students to independently construct a concept through problem presentation, formulation of hypotheses, data collection, analysis, and making conclusions.

Resurreccion (2014) explained that learners performed better in analysis, synthesis, and evaluation levels with regard to the use of audio-visual instructional materials in lessons. Similarly, Sulisworo & Syarif (2018) revealed that, the use of video technology in collaborative learning at secondary schools in the rural area can significantly develop the critical thinking skills of learners. Haryani et al (2021) observed that, teachers ought to use multiple resources to help them adequately integrate the skills of creativity, critical thinking and problem solving in learners. Further, Sadidi et al. (2019) indicated that, there is a significant association between instructional materials and enhancement of physics students' critical thinking skills.

Osborne (2014) outlined practices that foster the teaching of critical thinking skills in a science classroom, as follows:

i. Provision of opportunities that engage learners in critique, argumentation, and questioning. These, not only help build learners' understanding of science, but also develop their ability to reason scientifically and think critically.
ii. Driving learners to criticize or challenge knowledge already framed.
iii. Critically evaluating evidence.

iv. Responding to learner's prior knowledge and misconceptions (alternative frameworks) about scientific ideas.

Osborne further noted that science should naturally challenge learners thinking by inviting critical questions. As such, boost their problem-solving capabilities and enhance their creativity.

5. Critical Thinking Related Studies in Physics Instruction

Studies in physics instruction relating to classroom teaching of critical thinking skills have been carried out across the globe, as well as within the country (Kenya). A number of these studies are herein reviewed. The reviews focusses on the nature of study, setting & context, the findings, conclusions and recommendations made.

Luiz, (2017) Nanjing China, in a study titled, *"The Role of Critical Thinking in Science Education,"* noted that, critical thinking is of great potential in science education. As a result, classroom strategies based on critical thinking principles is paramount for instruction. According to his study questioning, critique, and argumentation are deemed the most important classroom strategies that foster learner critical thinking skills. Luiz further highlighted that, since the 1980's critical thinking as a specific course has been more and more explicitly integrated in the educational curricula of various countries. However, the integration failed and part of the reasons for the failure was that teachers lacked a clear idea about critical thinking, since the meaning ascribed to it in different contexts is rarely explicit.

Cassum et al (2013), in a study on multidimensionality of critical thinking noted that, critical thinking is a phenomenon of worldwide importance, a desired outcome in education and its acquisition by learners considered a major responsibility of educators. However, educators find it challenging if their own grasp of critical thinking skills is not well grounded. As a result, beyond equipping learners with critical thinking skills, teachers ought to be of sound critical thinking capabilities. Their arguments on multidimensionality of critical thinking are summarized in figure 1.

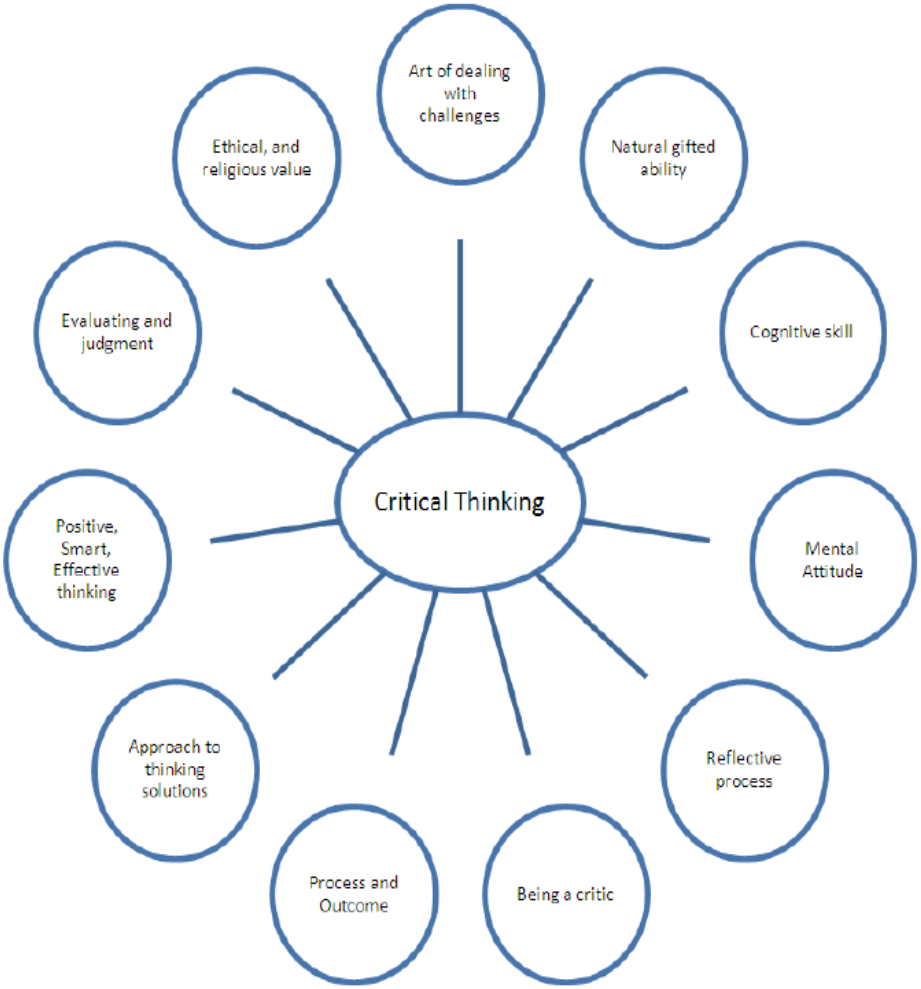

Figure 1: Multidimensionality of Critical Thinking
(Source: https://bit.ly/3sryiQm)

Tiruneh et al (2016) in a study on *"Measuring Critical Thinking in Physics: Development and Validation of a Critical Thinking Test in Electricity and Magnetism."* Measured critical thinking skills of learners in the topic electricity and magnetism. They developed a research tool namely Critical Thinking skills in Electricity and Magnetism (CTEM) test, which was administered to learners. The findings of the study pointed out that, CTEM test effectively measured critical thinking skills of learners in the topic (Electricity and Magnetism). As such, they concluded that, the tool was a good basis for empirical research focusing on integration of CT skills within specific subject matter instruction. Furthermore, it was a motivation to teachers in overcoming the challenges of monitoring and quantifying critical thinking skills of learners.

Sadidi, et al. (2019) Dresden Germany, in a study titled, *"Teaching Critical Thinking in the physics classroom: High school students thinking about antimatter."* Focused on enhancing learner critical thinking skills through effective teaching. They employed Merril's First Principles of Instruction model. The model consists of five interrelated phases of teaching, as follows:

1. Engage learners in real world problems.
2. Activate learners existing knowledge as a foundation for new knowledge.
3. Demonstrate new knowledge to learners.
4. Give learners an opportunity to apply the new knowledge.
5. Allow learners integrate the new knowledge to their everyday life.

The findings of the study indicated that, Merril's First Principles of Instruction led to improvement of critical

thinking skills of learners. Thus, the researchers concluded that for sound acquisition of critical thinking skills in physics instruction, teachers need to employ effective teaching model (Merril's First Principles of Instruction for this case). Similarly, the use of an effective teaching model is explained by Wartono, et al (2019) Malang, Indonesia, in a study titled, *"How are the Physics Critical Thinking Skills of the Students Taught by Using Inquiry-discovery Through Empirical and theoretical overview?"* The study was set to establish the significance of inquiry-discovery learning model vis-a-vis the acquisition of critical thinking skills by learners in physics instruction. The study established that critical thinking skills of learners taught through the model was higher than those taught using conventional methods, they also participated more actively in the learning process. The researchers concluded that employing inquiry-discovery learning model in physics instruction generated higher critical thinking skills in learners. Thus, recommend the use of the model in physics instruction. Basically, Inquiry-discovery learning model rests on learner's empowerment to discover through experiences, teachers are not at the centre of instruction but learners.

Erceg, et al. (2013) in a study, *"Probing student's critical thinking processes by presenting ill-defined physics problems,"* sampled and assessed two hundred and seventy-six (276) students in secondary schools and universities in Croatia. In the study learners' critical thinking skills were explored basing on their responses to two open-ended ill-defined physics problems meant to elicit their awareness regarding the meaningfulness of problem statements and solutions. The findings of the study indicated that the level of students' critical thinking skills was low, regardless of their educational level and curriculum. Consequently, the researchers concluded that inadequate critical thinking skills in learners was a deeply rooted problem in educational systems, thus the need for formulation of mitigation measures.

Arori (2010) in a study titled, *"Attitudes of physics teachers towards the teaching learning process in secondary schools in Nyacheki division, Gucha district, Kenya."* Examined attitudes of physics teachers towards the teaching - learning process in secondary schools in Nyacheki division, Gucha district, Kenya. The study revealed that good attitudes and practises in physics teaching are expected to promote critical thinking and problem solving. Similarly, Mutai (2015) in a study titled, *"Effects of Gowin vee heuristic teaching strategy on secondary school students' conceptual understanding and metacognition in the topic of moments in physics, in Uasin Gishu County, Kenya."* Observed that, hands-on approaches that encourage critical thinking led to an increased understanding of physics. As such, hand-on approaches ought to be integrated in physics instruction, to realize sound acquisition of critical thinking skills by learners.

Mukekhe (2019), in a study titled, *"Perspectives on Relevance of Physics Teacher Education Programmes in Relation to Pedagogic Skills of Student Teachers in Public Universities in Kenya."* Noted that in as much as the objectives of physics teacher education programmes are deemed relevant to acquisition of communication skills, salient areas of the programmes addressing problem solving abilities, critical thinking skills and integrity ought to be entrenched in the objectives of physics teacher education programmes. In the current Kenyan secondary school physics curriculum, acquisition of critical thinking skills by learners is only mentioned as an objective in the syllabus and no emphasis made beyond that, especially on how to teach, when to teach, resources for teaching, amongst others.

Mavu (2021) in a study on, *"Information Communication and Technology (ICT) Integration in Secondary School Physics and Its Effect on Students' Physics Academic Performance in Mombasa County, Kenya."* Found out that teaching using ICT improved learners' academic performance, as it helped in promoting their problem-solving skills and the ability to think critically. Consequently, the use of ICT resources in physics instruction need to be embraced by teachers of physics.

Hussain, et al. (2011) examined the effect of *"Peer group Activity-based Learning"* on academic achievement of secondary school students in physics subject. The study employed an experimental and a control group. The findings of the study indicated that, the experimental group performed better than the control group. Similarly, they were also significantly better in the domains of knowledge, comprehension and application. Consequently, the researchers concluded that, peer group activity-based learning was more effective in fostering the acquisition of application skills (a component of critical thing) as compared to the traditional lecture method. As such, there is need for physics teachers to employ the strategy in order to foster learner acquisition of critical thinking skills.

Permana et al (2019) Universitas Muhammadiyah Malang, Indonesia, in a study aimed at finding out acquisition of critical thinking skills by learners, investigated the contributions of three predictor variables, that is mastering of concepts, academic ability, and analytical skill. The findings were as follows, mastering of concepts contributed 3.84% towards the achievement of critical thinking skills, academic activity contributed 32.54% and analytical skill contributed 54.26%. It is evident that analytical skill contributed the most towards the achievement of critical thinking. The results of the study

form a good reference for designing learning processes aimed at empowering learner's critical thinking skills.

6. Challenges facing the teaching of critical thinking skills in physics instruction

Teachers of physics face a number of challenges in classroom teaching of critical thinking skills. Rutto (2023), University of Eldoret, in the study, *"The extent to which critical thinking skills are taught in physics lessons in secondary schools of Transnzoia county, Kenya."* Identified the following as the major challenges:

1. Lack of immediate real-life experiences of what is taught.
2. Large number of learners per class
3. Negative attitude of learners towards physics subject
4. Time constraints in cases of a shared science laboratory.
5. Inadequate instructional resources for teaching the skills.
6. Non homogeneity in learners' abilities

The challenges were broadly categorized into, learner and administrative related challenges.

7. Conclusion

This article has given an insight into critical thinking in physics instruction. It has defined critical thinking from varied perspectives, explored the history & nature of critical thinking, explained effective strategies for teaching critical thinking in physics lessons and the possible challenges faced in the teaching process. A review of studies relating to the teaching of critical thinking skills has also been explored. Basically, enhancement of learner's critical thinking skills is paramount, consequently teachers of physics are obliged to incorporate the teaching of the skills in their lessons. This will go along way into promoting a critical thinking society vital for worthwhile existence.

8. Recommendations

For sound teaching of critical thinking skills in physics instruction, the following recommendations are made:

1. Teachers of physics ought to incorporate instructional strategies that foster the teaching of critical thinking skills in their lessons. The strategies include, simulations, Socratic questioning, use of analogies, laboratory experiments, group learning, scaffolding, inquiry-based learning, project-based learning and problem based learning.

2. Teachers of physics need to regularly employ instructional resources that enhance the teaching of critical thinking skills in their lessons.

3. The ministry of education, through relevant entities like the Teachers Service Commission and the Centre for Mathematics, Science and Technology Education in Africa (CEMASTEA) need to organize periodic in-service training for secondary school teachers of physics aimed at boosting their pedagogical knowledge towards the teaching of CT skills.

4. Curriculum developers for secondary school teacher training. For instance, universities and the Kenya Institute of Curriculum Development (KICD) ought to develop or innovate existing curricula to include more training content for teaching critical thinking skills. This will go a long way in equipping physics teacher trainees with adequate pedagogical knowledge for teaching critical thinking skills.

5. Authors of physics course books, teachers' guidebooks and other relevant instructional books ought to include adequate content for teaching critical thinking skills in physics lessons.

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