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Review Article

Alternative learning models for resolving arguments in science laboratory work: Selection, integration, and implementation of generic components

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To investigate the present trends and gaps in science/physics laboratory work, a thorough literature review was conducted. Additionally, list the typical generic elements seen in science lab projects. Create alternative learning models as well to direct the choice, incorporation, and application of general science/physics laboratory session components. Additionally, to modify pedagogies, particularly guided-discovery, and to present alternate techniques of triangulating with other generic components of laboratory works and of deriving and choosing study variables. The study used a variety of techniques. First, a quick introduction to science and science/physics education, educational theories, and four fundamental learning theories, with an emphasis on how these relate to science laboratory practice.

Keywords: Guided-discovery, laboratory, learning theory, pedagogy, science education

1. Introduction

Educational policies and curricula materials state excellent learning outcomes for students, but science education studies have realized that the expected learning outcomes are hardly achieved by many students (Baloyi et al., 2017). As well studies indicated that not only students, but also school teachers have limitations in science education in terms of content knowledge, nature of science, and pedagogy to teach science (Blanchard et al., 2008). The reason is as students, teachers are not sufficiently learning the basic concepts, procedures, and natures of science they are supposed to know (Ramarian, 2016). As a result of this, different studies consistently have shown that both students and school teachers have less clear ideas about how science operates or how scientific knowledge is developed. The study conducted by Adisu & Abebaw (2021) on in-service primary school science and mathematics teachers indicated teachers have naïve views about Nature of Science [NOS] and Process Skills [PS].

Some of the factors affecting students learning and teachers teaching in science/physics education are categorized into student-related, teacher-related, and school (college) related (Badri et al., 2013). Of the three, school/college-related factors such as curricula and materials-related factors are dominant effects on students learning and teachers' teaching (Badri et al., 2013). For instance, as noted by Gurinder (2014) the availability of laboratory apparatus in school or college constrain teachers' teaching, students' thinking, and practicing of process skills, and reaching specific scientific results. The reason is that, in science education, laboratory work is the prominent learning environment that promotes students learning.

In addition, it promotes practicing science process skills, cultivates students' construction of alternative knowledge, and understanding of science, and motivates students toward science (Zudonu & Njoku, 2018). According to Nigussie et al. (2018), in order to attain the objectives of science/physics education and ensure the quality of science education, laboratory work in science has a prominent role. Thus, science/physics education curricula should appropriately select, integrate, and implement generic components to attain the goals of science education. Some of the generic components identified in science education laboratory works are forms of laboratories, pedagogies, contents, nature of science (NOS), and process skills (PS) being taught (Baloyi et al., 2017).Using models of learning that guide selection and integration of generic components is the main component in science laboratory lessons (Addisu et al., 2021). However, the components are less integrated and implemented in science education laboratories.

In science education, the appropriate integration and implementation of generic components make both teachers and students well-informed about science and balanced decisions makers about how science impacts their lives and to use scientific knowledge to solve problems (Lederman, 2011). And it opens an opportunity for students to reflect on the real picture of what scientists do in investigating scientific findings, and minimize students' science illiteracy (National Research Council (NRC), 2012). However, studies indicated that there are less internationally accepted integration of generic components and models of learning used to guide selection, integration, and implementation of components in science laboratory work (Adisu & Abebaw, 2021). Due to these, there are gaps in the selection, integration, and implementation of generic components in science laboratory work. In addition, different scholars select, integrate, and implement differently (Nigussie et al., 2018; Shimeles, 2010). One of the implications is that laboratory work materials are overloaded by contents (Nigussie et al., 2018) and less integrate other important components such as forms of laboratory, pedagogy, NOS, and PS. Due to these, limitations, there is less clear debate about the integration of generic components and their successes in terms of students learning outcomes (Baloyi et al., 2017; Clough, 2011).

This paper seeks answers for the following research questions:

RQ 1) What are the implications of basic science/education philosophies and theories of learning for science laboratory work?

RQ 2) What are common generic components of science/physics laboratory work?

RQ 3) How are generic components of the science laboratory integrated and implemented?

RQ 4) What alternative models are used to guide the selection, integration, and implementation of generic components of science/ physics education laboratory work?

RQ 5) What alternative method is used to derive and select study variables (dependent and covariates) in science laboratory work?

1.1. Objectives

The objectives of this study are to extract implications from each basic education philosophy and theory of learning for the development of science laboratory sessions. In addition, explore common generic components of science laboratory work and their mode of integration. Moreover, based on the implications of theories of learning and gaps identified in the area, develop alternative models of learning to guide the selection, integration, and implementation of generic components. Furthermore, based on models of learning, pedagogies used in science laboratories were modified. Parallel to this alternative integration of generic components demonstrates for science/physics laboratory sessions. In addition, propose an alternative method to derive and select dependent and covariates in science laboratory work.

2. Methods

This study carried out a systematic review of literature in science (physics, chemistry, and biology) education laboratory work. As suggested by Moller and Myles (2016) the review includes the identified study works both empirical conducted in schools, colleges, and universities, and a theoretical review of the literature. In addition, the Ethiopian college of teachers' education physics laboratory curricula overviewed in terms of selection, integration, and implementation of generic components. Hence, the study used different inclusion criteria to select related literature in the area. The date of publication of relevant materials is not the main criterion to exclude, but rather identifies and captures the development, progress, trends, and gaps in the history of science education laboratory work, and any relevant materials used (Boland et al., 2014). Because of the fact that some of the concepts and/or problems stated in the so-called literature are still hot and less solved.

The study followed the following procedures, according to the suggestion given by Boland et al. (2014) and Moller and Myles (2016) first job distribution for the review team conducted, and then a protocol to search and select related literature developed. Finally, a conceptual framework was developed to guide the study. Based on the job distribution, the first author searched related literature and a developed draft of the study. The second and third author screen and coach the work independently that proposed by the first author. The fourth author acts as a tiebreaker or criticizes and edits the work. According to the conceptual framework, the study starts searching literature contents related to philosophies of education, and theories of learning that are conducted in terms of critical overview in science laboratory work, comparison of theories of learning, implementation of different pedagogical and forms of laboratory, and implicit or explicit approaches of NOS and PS. Finally, the study reported the study findings (gaps) and alternative models in terms of tables, figures, and in text.

3. Literature Review

3.1. Science and Science Education

As noted by Wilson (1999), science is a systematic enterprise that builds and organizes knowledge in the form of testable explanations and predictions about the universe. The National Academy of Sciences (2008) defines science as it is the use of evidence to construct testable explanations and predictions of natural phenomena and that knowledge generated through the practicing of the scientific process. In view of this study, science can be defined as, it is our knowledge acquired and/ or constructed about natural phenomena, however, achieved through interaction with nature, society, and practicing of different processes and skills.

Though students learn science from KG to tertiary educational levels, the nature of science and the processes that take place in science is not well understood by students, and teachers (Baloyi et al., 2017; Ramarian, 2016). Due to these, there are conflicts in the minds of students and teachers about what are science and the nature of science. As a result of this, global studies like UNESCO PROAP (2001) suggested, teaching science is important in many ways such as knowing the role of science in society and appreciating the cultural conditions, and knowing the conceptual inventions and investigative procedures in science. In addition, it is used to understand the interrelationships of science, society, and ethics. Moreover, it is used to understand the interrelationships of science and humanities, then to feel comfortable when reading or talking about science. Thus, developing science education curricula (textbooks, modules, and laboratory manuals) special attention is needed about integrating the meaning and nature of science and the processes that take place in it.

The philosophy of science education includes the instruction aspects in addition to the contents of science, the nature of science, and the processes employed in science. That is why; the epistemological position of science education is to increase the literacy of students/society about science. Some of the epistemological stances of science education are knowledge of science constructed by the student rather than acquired, and all knowledge is the result of discursive practice. In addition, every culture has its own distinctive mode of apprehending the world and its own way of knowing or constructing knowledge. Moreover, all individuals are comparably gifted in their innate ability to acquire and/ or construct knowledge/ science (Levitt, 1999).

According to Bohr (1934), the purpose of physics (science) is not to disclose the real essence of natural phenomena, but also to track down the relations between the diverse aspects of experience that are attained by the different practices in society. Thus, physics education promotes conceptual change and a deeper understanding of scientific ideas and practices of society (Dedes, 2005; Dedes & Ravanis, 2008). In addition, it is used for fostering public understanding of science (Osborne, et al, 2002) and for positively impacting students' attitudes and interest toward science (Solbes &Traver, 2003). Therefore, when developing science/physic education curricula, and conducting research in science/physics education, its generic components and learning outcomes should be critically analyzed to achieve educational objectives.

3.2. An over View of Basic Educational Philosophies

As noted by Marsh (1992), philosophy is a source of direction found to guide educational activities. Therefore, philosophies of education are the guiding lines to derive theories of learning, methods of instruction, and objectives of learning would drive from. According to Marsh, there are eight basic educational philosophies such as idealism, realism, pragmatism, existentialism, paternalism, essentialism, progressivism, and reconstruction. According to Johnson et al. (2008), there are five philosophical schools of thought in education such as idealism, realism, constructivism, pragmatism, and existentialism.

According to the authors mentioned above, realism focused on the objective reality students' acquired, and idealism focused on the subjective reality that students would develop/ construct. While, pragmatism focused on interactive and tentative reality which works best to the condition, and existentialism focused on choice and practiced reality in society. In addition, paternalism is focused on mastery of content, and essentialism is focused on developing skills and competent individuals. Moreover, progressivism is focused on the active and developmental process of learning, and reconstruction is focused on improving/changing society based on individual needs and on issues related to the needs of society. Constructivism is a philosophy of education beliefs on alternative knowledge constructed based on interactions with the environment and other people (Draper, 2002). It focused more on the process of learning than the product of learning. Therefore, when developing science education curricula, and conducting research in science education, the basic educational philosophies should be critically analyze to guide the study and to achieve educational objectives. Because they tell us the type or form of knowledge acquired and/ or constructed and the method to achieve these objectives.

3.3. Epistemological Perspectives of Educational Philosophies for Science Laboratories

Epistemology is an area of philosophy that examines questions about how we know what we know, i.e. it is a model (process) of knowledge construction. According to Johnson et al. (2008) in view of education, idealism is the idea (content) centered rather than subject or child-centered. In this perspective, material (the content to be taught or the behavior to be achieved) is central to learning. Learning to this view is the acquisition and/or construction of knowledge from their classroom/laboratory experience via interaction of society (teacher and students), learning materials (curricula), and natural phenomena. Standardized tests, serialized textbooks, and specialized curriculum are the central activities to achieve the objectives (Johnson et al., 2008).

Realism is context centered rather than content centered, it focused on the meaning constructed from the environment/ natural phenomena. Thus, learning means more acquired through the process of transfer in classroom/laboratory experience based on contents in curricula materials. Therefore, the instruction is more focused on lecture, discussion, and imitation to acquire or transfer knowledge (information).To achieve the objectives, the role of the teacher and curricula are to present context in a systematic and organized way. However, it used standardized tests, serialized textbooks, and specialized curricula for each discipline. In this respect, realism (objective reality) is similar to idealism (subjective reality) (Johnson et al., 2008). Constructivism is a philosophy of education believes that learners develop their own knowledge based on interactions with their environment and other people (Draper, 2002). Thus, it understands learning as an interpretive and building process of knowledge by actively interrelating with the physical and social world (Fosnot, 1996). It assumes the role of teacher and curricula materials as guides or supportive meanness. Hence, in this view, the teachers concentrate on showing what way or how they learn the concepts in science, and to facilitate and negotiate to mean, rather than to dictate an interpretation (Driscoll, 2005).

Pragmatism as a philosophy of education stresses applying knowledge or using ideas for solving the problem at hand and prefers curricula that are interdisciplinary. Thus it considers learning as dynamic. For science laboratory work, it has implications that students try different alternatives to solve problems. In addition encourages teachers to use different methods of teaching, forms of laboratory, and implicit and or explicit approaches to understanding science. This is most closely associated with the constructivists' beliefs about how students learn best or solve the problem at hand (Johnson et al., 2008). Finally, existentialism is a philosophy of education focused on individual personal view development (Driscoll, 2005). This has also implication for science laboratory work; it implies that students develop honesty, ethics, and humanity when conducting studies in a science laboratory. At the end students develop how, when, and why service in society. Therefore, when developing science/physic education curricula, and conducting research in science/physics education laboratories, the epistemological position should be critically analyzed to achieve educational objectives. Because it has implications for science laboratory work in education.

3.4. Theories of Learning and their Instructional Implications for Science/ Physics Laboratories

3.4.1. Behaviorism

Skinner and Watson are the two major advocators of behaviorism. They studied how learning affected by changes in the environment and behavior could be predicted and controlled (Skinner, 1974). Behaviorists believed that visible behavior is worthy of scientific inquiry because they are observable and measurable (Bush, 2006; Jordan et al., 2008). The focus of this theory of learning is a change in behavior. Due to this, they concluded that, when the right environment is given, then it influences all learners to acquire an identical understanding/ change in behavior to the imposed phenomena (Lena, 2013; Weegar & Pacis, 2012). In view of the nature of science, behaviorism is based on a positivistic approach (objective reality). Because they have a reductionist view that is based on the relation between sensory- stimuli and the unique response (Pritchard, 2009; Webb, 2007).

The implication of this theory to use pedagogy and forms of laboratory in science/physics laboratory sessions is how to lecture and/ or demonstrate laboratory activities used to acquire the objective reality. In terms of science/physics laboratory, this theory has implications to develop a model of learning in the way that knowledge would be acquired by accommodation by using structured curricula/content and a controlled form of laboratory. Because the theory implies that, learning is represented more by factual, conceptual, procedural, and meta-cognitive knowledge, however, that are acquired via lecturing and demonstration and confirmatory (step-by-step.) forms of laboratory activity. Thus, the model of learning practiced in this theory is more conformational and/ or acquisition of knowledge by using structured curricula/content and a controlled form of laboratory.

Even though this theory has its merits in providing direction for social science or educational research in the way how to control and measure relevant variables, it has some limitations. The critique of this theory is that it only measures responses (products) in relation to imposed stimuli. In addition, it ignores human cognition like thoughts, feelings, intentions, mental processes, and so forth that humans do in their process of learning (Jordan et al., 2008; Rotfeld, 2007; Weegar & Pacis, 2012).

3.4.2. Cognitive

Jean Piaget was the advocator of cognitive. He defines learning as a developmental cognitive process that is constructed based on experience in relation to a person's stage of development, which contains both age and stage (Jordan et al., 2008; Weegar & Pacis, 2012). Piaget believed that cognitive development was a product of the mind that was achieved through observation and experimentation. It focused on the conceptualization of students' learning processes that how information is received, organized, stored, and retrieved by the mind in different age levels and stages of understanding/practicing process skills. In this view, learning is concerned not so much with what learners do (product), but with how the mind process information and come to acquire and/ or construct alternative knowledge by using different levels and type of science process skills (Lena, 2013; Jonassen, 1991).

In terms of science/physics laboratory, this theory has implications to develop a model of learning in the way knowledge would be acquired and/or alternative knowledge constructed either in a form of assimilation and/ or accommodation by using structured curricula/content and using either partially controlled and/ or uncontrolled form of laboratory. However, this theory has its strength, but it has some limitations, such as it used structured curricula as behaviorism, and it is difficult to measure different ages and developmental stages' cognitive processes at the same time or with the same assessment tools (Weegar & Pacis, 2012).

3.4.3. Social-Cognitive

Albert Bandura is a cognitive psychologist who developed the social-cognitive theory. The theory assumes that people learn by observing and imitating other people's behaviors and reactions (Bandura, 1977; Lena, 2013; Schunk, 2012). According to Bandura, to attain learning through observation, the processes of learning include attention, retention, reproduction, and motivational processes (Lena, 2013). Thus, in the social-cognitive, observational learning or modeling operates as an informative function. Consequently, it provides a model of thought and action to convey information about the rules for producing new behavior (Schunk, 2012). In addition, information about the structure of behavior and environmental events should transform into a symbolic (model) to serve as a guide for action in the teaching-learning process. Therefore, this theory of learning has many educational implications such as learning is based on social practice that occurs under various circumstances through subsequent modeling of certain behaviors, ongoing and mutual interaction between a person, environment, and previously learned behavioral patterns (Lena, 2013; Schunk, 2012).Though this theory has its strength, it has some limitations, such as it is difficult to measure different models students develop at the same time or by using the same assessment tools in a class/ laboratory work (Weegar & Pacis, 2012).

3.4.4. Social Constructivism

Lev Vygotsky extended the developmental theory of cognition to sociocultural (socio-cultural) cognition. The concept of sociocultural cognition presumes learning occurs within a cultural context (environment) and involves social interactions (Lena, 2013). That means, the mind is not only inside the learner, but also it is outside society. Hence, in terms of the process of knowledge development, the theory is sometimes said to be social-constructive. In addition, according to Vygotsky (1986), the type of knowledge is more of constructed than acquired via social discourse (Pritchard, 2009). Hence, in terms of the knowledge developed, the theory is sometimes said to be constructivist (Weegar & Pacis, 2012). However, according to Vygotsky, knowledge is constructed through different stages and processes, like cognitive theory (Lena, 2013). The cognitive tells us a step-by-step process, however, sociocultural cognition is related to the interaction of culture/ people, environment, and individual thinking and experience to develop mental processes adaptively and effectively. Due to this process, the social constructivism theory has developmental processes (Freeman & Company, 1997).

According to Vygotsky, the developmental process of mental functions is categorized into two such elementary and higher/ complex mental functions. Elementary functions are categorized as attention, sensation, perception, and memory. In another dimension, elementary functions break down into the formation of concepts, application of concepts to new objects, free association of concepts, and management of concepts in the formation of judgments. In addition, higher/ complex mental functions are categorized into different stages such as associative, collections, chain, diffuse, and pseudo concept. In each stage, there is the contribution of society/ culture and environment that represented in terms of a more knowledgeable person either is a teacher, parent, peer or even sometimes computers to make discourse and develop alternative knowledge (Lena, 2013).

Socio-cultural or social constructivism does not explicitly describe the typical education model of what teachers do to transmit information to their students, however, the theory suggested student plays an active role in learning and discovery (comprehending the learning material and problem at hand) in terms of collaboration with teachers, and peers (Rummel, 2008). In addition, teachers are highly expected to be competent to scaffold individual students according to their capabilities. Moreover, teachers also need to summarize, question, clarify and predict the study objectives (Lena, 2013). According to socio-cultural/ social constructivism, schools are small societies where students practice social interaction with each other, with teachers, and with learning curricula. The classroom/ laboratory is used as an environment students will pass through different stages of the zone of proximal development to construct alternative knowledge (Lena, 2013). Thus, according to this theory, instructional methods may include guided discovery, demonstration, concept injection, semi-structured and/or open forms of laboratory, and pose problems to complete the work. Hence, this theory has implications to develop a model of learning that, students acquired and/ or construct alternative knowledge by using either open or semi-structured curricula/content and free or semi-structured forms of the laboratory.

In addition, the theory has recommended teachers summarize, question, clarify, and predict the study objectives (Lena, 2013).Overall, the application of Vygotsky social constructivism has an implication for teaching methods or to help the learning outcomes of students. However, the theory has limitations, it assumes each individual thinks and behaves in a similar fashion at the same age and stage as Piage (Lena, 2013). Another limitation is the zone of proximal development. In the zone of proximal development, teachers help each student to accomplish his or her individual potential; however, at once in the classroom with different students with different capabilities, teachers are challenged to provide different scaffolding activities. Hence, it is difficult for teachers to gauge each student's progress and apply the zone of proximal development. Therefore, it is challenging to develop semi-structured/ open curricula that are appropriate for individual learners in a science laboratory. Furthermore, in terms of measurement and evaluation mechanisms used in education, measuring all alternative forms of knowledge constructed by individual learners makes it difficult (Schunk, 2012).

3.5. Implications of Theories of learning in development models for science Laboratories

Behaviorists believed that meaning exists in the external world separate from personal experience (objective reality). Thus, all instructional goals are framed in specific and observable behavior. In this approach, the focus of instructor is present the intended behavior to be achieved. The role of student is striving to attain instructional presentations and material, and then use them to create performances, which indicate attainment of correct mental models. Assessment and evaluation based upon individual tests and performances to demonstrate mastery of entities, contents, activities, and processes. To achieve this, drill, structured forms of laboratory, and practical tutorials (informed laboratory contents before class) are activities conducted before moving on to the next learning objective (Shield, 2000).

To do complex process and further investigations, a prior knowledge (concept injection in terms of lecture or demonstration) about the methods and concepts are mandatory. In this theory, the focus of instruction is to allocate the process of how rather than to achieve what. The role of student is to attain the instructional presentations conducted by teacher and materials, but that is used as starting point to construct an alternative knowledge. Semi-structured assignments (curricula or forms of laboratory) are alternative methods to facilitate learning. In addition, activity based tutorials are alternative methods to activate students' cognitive learning before moving on to the next learning objective. Assessment and evaluation based upon individual tests and performances to demonstrate activities, and processes in physics laboratory (Weegar &Pacis, 2012).

In view of social-cognitive theory, learning occurred from social experience under various circumstances through subsequent modeling of behaviors. Thus, learning is ongoing and mutual interaction between a people, social environment, and previously learned behavioral patterns. In this theory observation and modeling are the process takes place for learning. Therefore, instructions set in the way that teachers demonstrate, students observe, and finally execute or developing models (Bandura, 1977; Schunk, 2012)..

Thus, instructional design much holds that, the learners construct an alternative understanding from open or semi-structured curricula and/ or from their experiences via interaction with nature and society. Thus, instructional goals are framed in terms of kinds of activities in which students engage and on the ways they reflect the results of activity (Lena, 2013; Weegar &Pacis, 2012). Therefore, the instructional design is interactive problem-based, and the instructional environment (laboratory) designed in terms of empowering their own learning either in forms of semi-structured or open form. Therefore, assessment and evaluation focused on the process of learning than product form of learning. Thus, may semi-structured / open curricula and semi-structured/ or open forms of science laboratory used.

3.6. Alternative Model of Learning Extracted to Guide Science/Physics Laboratory Work

Based on the overview of educational philosophies, and theories of learning this study developed alternative models of learning that guides selection, integration, and implementation of generic components' in science/physics laboratory work. In view of this study, learning is a process of constructing and / or acquiring knowledge that attained due to application of integrated generic components such as pedagogies, forms of laboratories, and science(contents, NOS and PS), and assessment mechanisms present in section 2.10.2. In these models, curricula refer to content/science, process skills, and nature of science. Whereas forms of laboratory may refers to the arrangement of learning environment that may include pedagogy, and assessment mechanisms used in science laboratory. Behind each model of learning there is/ are theories of learning and educational philosophies. Thus, there are pedagogies that fit for each model.The models of learning presented in section 2.10.2 used as guideline to modify pedagogies, especially guided-discovery, and to triangulate theories of learning with pedagogies and forms of laboratories. Then, to develop alternative mode of instruction/lesson plans that contain/ integrate different pedagogies, forms of laboratory, and contents being taught. Because, the models have implications to select, integrate, and implement generic components in science laboratory work.

3.7. Pedagogies Used in Science/physics Laboratory

3.7.1. Conventional - traditional method in physics laboratory

The traditional methods used detailed step-by-step experimental approaches either in lecturing and/ or demonstration that were pre-designed by a teacher. The experiments were carried out in controlled forms of laboratories to attain conformational results. According to (Sundberg &Moncada, 1994), when using conventional pedagogy in the laboratory, students completed assignments prior to a class designed to prepare them for the laboratory activity and quizzed on previously informed concepts by lecturing and/ or demonstration at the start of the class. Even though this method has the advantage to cover the content of the curriculum, it is criticized as it is a more structured and teacher-centered method and/or cook book (Mcdermott, 2013; Mosca & Howard 1997). As a result of this, it less engages students to practice process skills (meta-cognitive knowledge) and fewer helps students to construct alternative knowledge (Mayer,2004). Its major emphasis is on the physical principles being taught (confirmation of content and practice). It fit with the model of learning that, knowledge is more of acquisition/confirmation by using structured curricula and controlled forms of the laboratory.

3.7.2. Free discovery methods

The Discovery method is a method of teaching that focused on active hands and minds-on learning (Baloyi, et al, 2017; Dewey, 1916; Piaget, 1954). The main attributes of discovery learning are: exploring and solving problems, and creating and integrating generalized knowledge (Dewey, 1997; Piaget, 1973). In addition, it is student-driven activities in which students determine the sequence and frequencies of actions (Baloyi et al., 2017; Bicknell-Holmes & Hoffman, 2000). The focus of this method is on the process of learning than on the content being learned or taught (Bonwell, 1998). Thus, it supports cognitive psychologists' view that failure is central to learning (Schank & Cleary, 1994). Due to these, it is an active method of teaching (Mosca & Howard 1997). The model of learning fit for this pedagogy is knowledge construction by using open curricula and free forms of laboratory.

Free discovery has limitations such as it needs a high cognitive level of practicing scientific process skills, and increasing the cognitive load of learners (Mandarin & Preckel, 2009). Thus, implementing free discovery/exploration learning is difficult to implement on beginning learners or students with limitations in practicing process skills, because they may have no necessary skills to integrate the new information with information they have learned in the past (Baloyi et al., 2017; Mandrin & Preckel, 2009).

3.7.3. Guided-discovery method

Guided discovery is the middle-ground effect of traditional (lecture and/ or demonstration) and discovery methods (Kirschner et al., 2006; Mayer, 2004). Because, it has the benefits of both traditional and free discovery instruction in such a way that: it is both cost-efficient and goal-oriented, students experience and explore learning in a collaborative manner, and discovery activities are provided with both direction and freedom in the classroom. In addition, it gives a chance for teachers to provide coaching, modeling some structure, and support (Kirschner et al., 2006; Mayer, 2004). In this method, students are confronted with a challenge and left to work out the solution on their own (Bruner, 1961; French 2006). Hence, it encourages students to practice science process skills, then to construct better alternative knowledge about the content being taught than only using conventional or free discovery methods (Sharif, & Hassan, 2012). The model of learning fit for this pedagogy is that, knowledge construction by using open or semi-structured curricula and semi-controlled or uncontrolled forms of the laboratory.

After the concept of guided discovery emerged, different scholars divided pedagogies used in science laboratories into different levels. For example, (Bianchi &Bell, 2008) divided the pedagogical approach used in science laboratories into four levels such as structured, semi-structured, guided, and open pedagogies. However, the division not clearly addresses the type of forms of laboratory and integration of other generic components; rather it focused on the presentation of contents and scaffolding activities. In addition, the activities conducted by the teacher and students less supported by theories of learning, different pedagogies, and forms of laboratories. Thus in this study, the limitations observed in different literatures were well addressed and alternative models were developed to well explain the guided discovery method. To support the modification of guided-discovery self-determination theory was used (Deci, 1975; Deci& Ryman, 1987). According to this theory, students have needs for proficiency, independency, and connection, which require the attention of the teacher. The reason is that when using any pedagogy proficiency, independency, and connection are the main variables to design instruction. The detail presented in the following section.

3.7.4. Modified guided-discovery

As study gaps stated above about guided discovery, this study modified guided discovery into three alternatives. To modify guided-discovery methods activities merged from traditional method either in lecture and/ or demonstration with free discovery (practicing different levels and types of process skills). Based on this, three alternative approaches of guided discovery were obtained. Namely: (1) Structured guided-discovery (SGD) (2) Semi-structured guided discovery (SSGD) (3) Scaffolding guided-discovery (SCGD)

Structured guided discovery (SGD) was obtained by merging lecturing from the traditional method with discovery activities from free discovery. In this method, knowledge is acquired and/ or constructed by using structured curricula/content and open/ uncontrolled forms of the laboratory. Since structured curricula give more emphasis to a structured mindset up/schema, but to conduct discovery activities (practice different levels of PS) open laboratory is selected.

Therefore, the mode of instruction includes concept injection by lecturing and poses problems, but the answer to the posed problem is reached by using an open laboratory. That encourages discovery activities.

Semi-structured guided discovery (SSGD) was obtained by merging demonstration activities from the traditional method with discovery activities with free discovery. In this method, the knowledge is acquired and/ or constructed by using semi-structured curricula and structured forms of the laboratory. In this approach, schemata are constructed by a demonstration of concepts, procedures, and the nature of science. Therefore, the mode of instruction includes demonstration and posing problems, then students are expected to construct theory and may re-set/ modify the arrangement of equipment, then try to answer posed problems. That encourages discovery activities.

The last modified guided-discovery method is scaffolding guided discovery (SCGD), which is obtained by merging activities from the traditional method either in a form of lecturing and/ or demonstration with activities from free discovery. This method is open for both teachers and students to interact with each other. The problem at hand, the curricula, teacher, and/or students forced the laboratory work to start. The preferable forms of curricula/presentation of content and forms of the laboratory are semi-structured. The instruction may start with pose problem, concept injection, or demonstration, then any scaffolding activities conducted by the teacher, and then gradually withdrawn, when students stop asking for help, that relates to the Zone of proximal development.

3.8. Science Laboratory in Science/physics Education

3.8.1. Definition of practical / Laboratory work in science / Physics

As noted by Hodson (1993, 2002), it is a bench work instructional method that requires learners to be active rather than passive. Hence, it is a place to conduct teaching and learning activities that involve students observing and /or manipulating real objects and materials (Millaer, 2004; Shimeles, 2010). In view of this study, the science/physics laboratory is an environment designed for learners either in a form of structured, semi-structured, or uncontrolled that is used to acquire and/or construct alternative knowledge via practicing science process skills.

3.8 2.The aims of practical work in science/ Physics education

According to (Hodson 1990, 1991), the aims of practical work are represented in terms of motivation by stimulating interest and enjoyment, teaching skills to enhance the learning of scientific knowledge, giving insight into scientific methods, and developing expertise in using it. In addition, science/physics laboratories are used to acquire existing knowledge, develop problem-solving skills (practicing processes to generate an alternative view), and understand the nature of science (Gott et al., 1986). However, different studies conducted in the area indicated that science/physics curricula or material (modules, laboratory manuals) less clearly articulated these issues (Boud et al., 1989). Curricula materials give more emphasis on content (Nigussie et al., 2018; Shimeles, 2010). Therefore, science/physics laboratory work is restricted to the acquisition form of knowledge and dominantly observational manipulative skills practiced such as verification, illustration, and demonstration (Shimeles, 2010). Due to these, the purposes of laboratory work were not well entertained in schools and colleges.

According to the critique conducted by Hofstein and Lunetta (1982, 2003) and Shiels (2010), and Gurinder (2014) most of the studies focused on few laboratory related skills, and measure factual or conceptual knowledge only not describe student abilities and attitudes, used standardized achievement tools which were not specifically designed to measure laboratory outcomes. In addition, most studies did not look at teacher behavior. Moreover, an experiment can be closed ended or open-ended and inductive when taught by different teachers, and the role of the laboratory manual is not studied. Furthermore, there are lack of measuring students' lab work in terms of hypotheses formulation and questions generating abilities. Most of the time conventional assessment methods used in laboratory. There are additional gaps in laboratory works that are not addressed by Hofstein & Lunetta, Shimleles, and Gurinder. Such as, the selection and integration of generic components of science laboratory work. Thus, there is unclear debate in the area. Therefore, this study focused on these gaps, i.e. explicitly articulating and integrating generic components based on the models of learning. In the following section the generic components are presented.

3.8.3. Forms of practical work in science / Physics education

For Woolough (1991), forms of laboratories are classified into four forms such as to exercise (confirm by practicing skills), experience (to feel the phenomena), demonstration (develop the argument or create an impression), and investigation (hypothesis-testing and problem-solving). In the same way, Boudet et al. (1989) classified laboratory works into three forms such as to conduct the controlled exercise, conducting experimental investigations, and conducting a research project. However, in this study, the classification/arrangement developed by Banich and Bell was used to triangulate forms of the laboratory with pedagogies and models of learning. The following table presents a triangulation of theories of learning, models of learning, pedagogies, and forms of the laboratory.

Table 1

Triangulation of forms of laboratories, pedagogies, theories of learning, and model of learning

Components		Types of pedagogies used in science laboratory				
		Traditional	Modified Guided-discovery			Free discovery
			SGD	SSGD	SCGD	
Forms of Laboratory	Controlled/ structured	√		√		
	Semi-controlled				√	
	Uncontrolled/ free		√			√ (If the teacher less intervene)
Basic Theories of Learning more applicable		Behaviorism	Cognitive + Social Constructivism+ Social cognitive	Social - cognitive + Social Constructivism	Constructivism + Social-cognitive	Social Constructivism
Models of learning proposed		Model-1	Model-2	Model-3	Model-4	Model-5

Table 1 indicates, as there are different forms of science laboratories, contemporarily there are different instructional strategies and theories of learning that alternatively fit with each other. Thus, when developing laboratory sessions/ science laboratory curricula different learning theories, forms of laboratory and instructional strategies used in laboratory should align. For example, controlled forms of laboratories are used for conventional method and semi-structured guided discovery. The model of learning fit for conventional is model one and model three for semi-structured guided discovery. In addition, the theory of learning fit for the conventional method is behaviorism and semi-structured guided discovery is the combination of Social-cognitive and Social-constructivism. The model of learning tells us the form of curricula/ content and laboratory.

3.9. Implicit and Explicit Approach of Nature of Science and Process Skills (NOS and PS) in Science Laboratory

There are debates on the explicit or implicit approaches to the nature of science and process skills (NOS and PS) in science education. However, in laboratory courses, the intergradations and implementation are less addressed. Different scholars used the explicit approach to NOS and PS and obtained a significant impact on students' understanding of NOS and PS compared to the implicit approach (Baraz, 2012; Yalcinoglue& Anagun, 2012). Contrary to this, the implicit approach of NOS and PS had a significant impact on students' understanding of NOS and PS compared to the explicit approach of NOS and PS (Bell, 2008).

Different studies used instruction-assisted approach of NOS and PS in science/ physics laboratories. For example, the study conducted by Cibik (2016) used a project-based approach to history and NOS and obtained a significant impact on students' understanding of NOS and PS. Similarly, Baloyi et al. (2017) and Sharif and Hassan (2012) used a guided-inquiry approach in a reflective question of NOS and PS and obtained a significant impact on students' understanding of NOS and PS. In another way, a study conducted by Yacoubian and Bou Jaoude (2010) used an explicit reflective discussion about NOS and PS and obtained a significant impact on students' understanding of NOS and PS. Of the three alternatives, the instruction-based approach of NOS and PS had a more significant impact on students' understanding of NOS and PS than explicit or implicit approaches (Baloyi et al., 2017).

The alternative integration is presented in table 2 below. The table demonstrates how contents, NOS, and PS are integrated with pedagogy, forms of laboratory, theories of learning, and models of learning. Hence, researchers or curricula developers used it as an alternative integration or based on the model presented to use another form of integration. The table demonstrated that in modified guided-discovery methods, the integration of NOS is implicit and activity-based and students answer questions based on the data they gather from the laboratory, whereas PS is explicitly presented before the start of laboratory work. It is a new approach by splitting both NOS and PS. In addition, the model of learning, pedagogy, and forms of the laboratory are triangulated with each other.

3.10. Assessment and Selection of Variables in Science Laboratory Work

3.10.1. Assessment and measurement in science laboratory work

Science/ physics laboratory courses are supposed to develop students' cognitive, psycho-motor, attitudinal, and/ or affective abilities related to experimental work in science/physics (Bloom, & Krathwohl, 1956). Thus, assessment is one of the generic components of science laboratory work (Hofstein & Lunetta, 2003; Tamir & Glassman, 1971). However, under assessment, measurement is the assignment of numbers for the category of observations /constructs of the study (Willson, 2005). In educational studies, the observations/ constructs under study are the impacts of independent variables (pedagogies, forms of laboratories, and other generic components) on dependent (learning outcomes and motivation) and/or covariates.

According to Hodson (1992), assessment implemented in science laboratories is classified into four functions: summative function, formative function, evaluative function, and educative function. The summative function of assessment is to provide an idea of the level of attainment of students at the end of a course. The formative function provides feedback to the teacher about the effectiveness of teaching and learning activities. The third function, which is an evaluative function of the assessment, is to give information about the curriculum experiences to the teacher, to assist the teacher in curriculum planning and decision-making. The educative function of assessment is to engage students in the learning process during the assessment. However, in science laboratory work assessment has not been given due importance by the science/Physics education researchers, college, and university instructors as far as developing and implementing appropriate strategies to measure the achievement of laboratory work (Khaparde & Pradhan, 2009).

In measuring variables of laboratory work in science education laboratory work different studies measure different constructs. Different studies measure the criteria and tool development to assess laboratory work. A few researchers have reported remarkable developmental work on laboratory performance tests and strategies for science/ physics laboratory courses (Burns et al., 1985; Gott &Duggan, 2002; Kruglak, 1958; Moreira, 1980; Theysohn, 1983). Also, Cole et al. (2019) developed valid assessment tools to measure critical thinking in physics laboratory work. However, developing valid tools for different laboratory contexts is highly criticized (Hofstein & Lunetta, 1982, 2003). In terms of learning variables, Tamir and Glassman (1971), measure

Table 2

Alignment of models of learning, pedagogies, forms of lab, NOS, and PS and contents in physics laboratory.

The Components of lessons and its presentation in physics laboratory					
Model of learning	*Pedagogies used in physics laboratory*	*Forms of laboratory fit for the pedagogy*	*Presentation of contents, NOS and PS*	*Presentation of question and answer for the question*	*Assessment used both formative and/ or summative*
Model -1. Knowledge can be acquired or confirmed in science/physics laboratory by using structured contents/curricula and controlled form of laboratory.	Traditional/conventional method	Structured with detail steps in lab manuals, and set equipment's in laboratory for the experiment	-Contents explicitly present by using lecture/ demonstration - PS, explicitly presented before experimental work start - NOS, implicitly integrated in activity-based approach that answered based on data	Teacher pose questions , but in advance answers known	More focused on acquired form of knowledge, in terms of contents, process, and NOS. Mostly used objective type.
Model-2. Knowledge can be acquired and/ or an alternative knowledge constructed in science/physics laboratory by using structured curricula/content and using uncontrolled form of laboratory.	Structured guided-discover (SGD)	Open, however guide lines about the how to set apparatus/ experiment in diagram given	-concepts injected (highlight/ lecture) - PS, explicitly presented before experimental work start - NOS, implicitly integrated in activity-based approach that answered based on data	Teacher pose problem, and answer to the questions are based on data propagated from the lab work and injected concepts	Focused on both acquired and alternatively constructed knowledge. Thus, any type assessment tools can be used

Table 2 continued

Model-3. Knowledge can be acquired and/ or an alternative knowledge can be constructed in science/physics laboratory by using semi-structured curricula and structured /controlled form of laboratory.	Semi-structured guided-discovery (SSGD)	Structured (demonstrate how to set up of laboratory materials)	-concept injection by demonstrative - PS, explicitly presented before experimental work start - NOS, implicitly integrated in activity-based approach that answered based on data	Teacher pose problem, and answer to the questions are based on data propagated from the lab work and demonstrated concepts	Focused on both acquired and/ or alternatively constructed knowledge. Thus, any type assessment tools can be used
Model-4. Knowledge can be acquired and/ or an alternative knowledge can be constructed in science/physics laboratory by using semi-structured curricula/content and semi-structured form of laboratory.	Scaffolding guided-discovery (SCGD)	Semi-structured, however guide lines, diagram, and laboratory set up given based on the request of students	-Pose questions related to contents - PS, explicitly presented before experimental work start - NOS, implicitly integrated in activity-based approach that answered based on data	Teacher pose problem, and answer to the questions are based on data propagated from the lab work, concepts injected /demonstrated concepts	Focused on both acquired and/ or alternatively constructed knowledge. Thus, any type assessment tools can be used
Model-5. An alternative knowledge can be constructed in science laboratory by using open contents/ curricula and open form of laboratory	Free discovery	Open, however nearby follow up how to use apparatus	-Pose questions related to contents -- PS, explicitly presented before experimental work start - NOS, implicitly integrated in activity-based approach that answered based on data	Teacher pose problem, and answer to the questions are based on data propagated from the lab	Focused on alternatively constructed knowledge. Thus, any type assessment tools can be used

laboratory work in terms of manipulation, self-reliance, observation, investigation, communication, and reasoning. Shulman and Timit (1973), measure laboratory work in terms of skills, concepts, cognitive abilities, understanding of the nature of science, and attitudes.

Similarly, Lee (1978) measures the functions of science laboratory work in terms of manipulative skills, processes of science, knowledge of the subject matter, nature of science, and attitudes, interests, and values. Office of Qualifications and Examinations Regulation [OFQUAL] (2009) states that, students need to be assessed through a controlled assessment on their ability to plan practical ways to answer scientific questions and test hypotheses; devise appropriate methods for the collection of numerical and other data; access and manage risks when carrying out practical work; collect, process, analyze and interpret primary and secondary data including the use of appropriate technology, draw evidence-based conclusions; evaluate methods of data collection and the quality of the resulting data. Also, some other studies measure the impact of laboratory work in terms of student understanding of uncertainty, measurement, and data analysis (Day & Bonn, 2011; Volkwyn et al, 2008). The studies conducted by Holmes and Bonn (2013), Karelina et al. (2000), and Gormally et al. (2009) measure laboratory work in terms of student development of scientific reasoning and experimentation skills.

Furthermore, in most studies, there is/ are no clear standards used to derive and select dependent and other related (covariates) in science laboratory work (Daniel et al., 2021a). That limits the effectiveness of laboratory work and increases the discrepancies between the objectives of laboratory work and the achievement of students (Shimeles, 2010). The cumulative effect of these limitations may mislead interpreters about the success of some selected pedagogies, forms of laboratories, and implicit or explicit integration of generic components in terms of students' learning outcomes and motivation. In addition, it greatly affects students' achievement. Hence, when conducting studies in a science laboratory in terms of the implementation of some selected generic components in the science laboratory, it is suggested to consider the triangulation of assessment methods with other generic components. Thus, this study based on the gaps in the area and proposed an alternative model to clearly integrate the models of learning, pedagogies, and forms of laboratories with assessment methods. The detail is presented in Table 2. As well alternative model was developed to derive and select dependent and covariates. The detail presented in the following section.

3.10.2. Derivation and Selection of variables in science laboratory work

In education, students learning outcomes are interpreted in terms of three domains such as cognitive (knowledge), psychomotor (skills), and affective (attitudes/ motivation) (Pritchard, 2009). However, studies conducted in the area lack conceptual frame work to guide the selection of variables (Addisu et al., 2021a; Doran, 1978). Thus, this study has developed an alternative model to derive and select dependent and covariates in science/physics laboratory work. However, before deriving and selecting variables for study, this study proposed a theoretical model. There are two models (assumptions) which guide the derivation and selection of variables of the study. The first assumption/ theoretical model are a different type of selection, integration, and implementation of generic components in a science laboratory in turn different type and level of learning outcomes. The second assumption is a different type of selection, integration, and implementation of generic components in a science laboratory in turn different type and level of association among variables. This means any study variables and association among variables are the interaction effects of independent/ generic components. The interaction effects study variables may be represented in terms of dependent and/ or covariates. In this study, the generic components are independent variables such as models of learning, forms of laboratory, pedagogies, contents, and NOS and PS. The following table presents the detail.

Table 3
Alternative methods to derive dependent and covariate in science laboratory work

Generic components	*P=pedagogy*	*F=forms of Laboratory*	*C= contents, NOS and PS in science*	*Px F x C =F x P x C= Cx P x F*
P= Pedagogy	-	F x P= PFLO (pedagogical and forms of laboratory orientation)	P x C=MC (mastering contents, PS, and NOS)	OLM (overall learning outcomes and motivation such as factual, conceptual, procedural, understanding about NOS, and motivation
F=forms of Laboratory	F x P= PFLO (different level pedagogical and forms of laboratory orientation)	-	F x C= PPS (practicing process skills, insight to develop lab skills in science)	
C= contents, NOS and PS in science		F x C= PPS(practicing process skills)	-	

Note. Adapted from NRC (2006), and Shimeles (2010), and reported as Adisu et al. (2021), and Addisu et al. (2021a).

In Table-3, F, P, and C are independent variables (genetic components). Whereas FxC=PPS, FxP=PFLO, PxC=MC, and P x Cx F=OLM are the combined/interaction effect of two or three independent/generic components, that may be dependent and /or covariates. In the above table "P" refers to different pedagogies used in the science/physics laboratory to support learning. "F" refers to different forms/arrangements of science/physics laboratory to support the learning of students in science/physics laboratory. In addition, "C" refers to contents being taught/ learned in the science/physics laboratory related to concepts, process skills, and the nature of science. PC refers to the interaction effect of forms of laboratory (F) and contents(C) in science. PFL refers to the interaction effect of pedagogy (P) and forms of the laboratory. MC is the pedagogy and contents in science/physics, and OLM. OLM refers to the interaction effect of three independent variables. In view of this study, FxPxC (OLM) was selected as the dependent variable. Whereas, FxP, FxC, and, PxC are selected as covariates. When the researchers focused on the integration of forms of laboratory and pedagogy, forms of laboratory and contents being taught, and pedagogy and contents being taught in the science laboratory, one of the component's effects was less achieved.

4. Conclusion

In science laboratory work, there are less internationally accepted selection, integration, and implementation of generic components. In addition, there is less clear model of learning used in almost all studies, and laboratory curricula. Moreover, there is less, even no models used to derive and select dependent and covariates. As result of these gaps, different scholars and curricula material developers select, integrate, and implement different types of generic components in science/physics laboratory. These gaps in turns limitation in science laboratory work in many ways such as there are less clear debates in the area in terms of successes of pedagogies, forms of laboratories, and explicit/ implicit approaches of NOS and PS. In addition, the limitation had negative impacts on students learning outcomes and motivation in science laboratory work.
Thus, this study conducted to minimize the gaps in area and clarify debates. To do this, the study developed models of learning that used to guide selection, integration, and implementation of generic components in science/physic laboratory work. In addition, based on the models, pedagogies, especially modified guided-discovery leveled in to new three alternative approaches. Moreover, the study demonstrates triangulation of generic components for science/physics laboratory sessions. Furthermore, derivation and selection of dependent and covariates demonstrated for study conducted in science laboratory work. Therefore, when developing science laboratory curricula or conduct empirical studies in science laboratory, using alternative models of

learning, derivation, and selection of variables of study, and alternative model of integration of generic components are suggested. In addition, modified guided discovery methods are suggested to implement in science laboratory work to clearly guide the activities due to clear model of learning that guides selection, integration, and implementation of generic components. That may clarify the debates in science laboratory work and simplifies science laboratory work in education.

5. Implication of the Study

The implication of this study for science education laboratory work is:

- In science laboratory, how basic education philosophies and theories of learning explicitly contribute to develop science laboratory curricula or session that represented in terms of models of learning to guide each activity in laboratory.
- Based on models of learning, how generic components in science education appropriately (implicitly and / explicitly) integrated.
- The study also explores some selected common generic components of science laboratory work and their mode of integration. This implies, in science laboratory work explicitly and/ or implicit integration of generic components addressed when developing science education laboratory curricula or session to effectively measure their impact on students learning outcomes.
- The other implication of this study is that, when conducting study in science laboratory work, theoretically the learning outcomes (dependent and covariates) derived and selected before they test empirically. To do this the study proposed two theoretical assumptions that used to guide selection of study variables. In addition, to measure the type and level of association among variables (independent, dependent, and covariates) with each other.
- Moreover, based on implications of theories of learning and gaps identified in terms of pedagogy, guided-discovery modified and levelled into three alternatives.

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