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What is the "Philosophy of Chemistry Education"? Viewing Philosophy behind Educational Ideas in Chemistry from John Dewey's Lens: The Curriculum and the Entitlement to Knowledge

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ABSTRACT

In several pieces of research literature and with chemistry teaching experience of the researcher at the school level, the researcher has identified, as opposed to skills pertaining to learning of chemistry, that a recent trend is observed where there is heightened emphasis on verbalizations in chemistry education, and an enhanced emphasis on the practical utility of chemistry. John Dewey is recognized as an established early advocate of contextual and practical knowledge. To analyze the common research framework, in terms of procedural and conceptual knowledge, the researcher utilized the tools which Dewey provided for discussing the knowledge of chemistry education. The researcher argues that by emphasizing the notion of operational skill, the tendency to treat procedural knowledge and conceptual knowledge as opposites, shall be avoided. The researcher further argues that it is important for the learners to accrue both computational skills as well as contextual knowledge, both of which are implicated in the knowledge of chemistry education.

KEYWORDS

Chemistry Curriculum, Chemistry Education, Conceptual Knowledge, Dewey, Operational Skill, Procedural Knowledge, Philosophy of Chemistry Education

1. Introduction

An international reform movement emerged in several countries for chemistry education during the 1990s (Apotheker, 2019). What chemistry content should be studied in schools, i.e., the basis of development of curriculum documents, traditionally, have been based mostly on methods, theories, concepts, notions, and results. Instead, the new trend, by the introduction of generic competencies, which can be noted in the chemistry curricula of Finland, includes communication skills, reasoning, problem-solving, and conceptual understanding, and aims to delineate the connectedness that chemistry practice and chemistry content entails (Wang, Li, & He, 2018).

Applied chemistry is oftentimes referred to as 'real-world chemistry' (Devetak, 2020). One expression of this trend is to make sure that the pupils can use the learned chemistry outside the test situation that they have understood within the four walls of the chemistry laboratory (Zembal-Saul & Vaishampayan, 2019). Increasing emphasis today is on both, applied chemistry and verbal knowledge. This is often motivated by the need of how the chemistry they learn in school makes students learn to connect to the life that is outside the classroom (Pagliaro, 2019).

Students never learn chemistry creatively by just memorizing empty formulas of immunochemistry or mechanochemistry. Chemistry learning instead is based on conceptual knowledge (Mahaffy, Krief, Hopf, Mehta, & Matlin, 2018). This attempt of involving students, and contextualizing the information is quite old (Markic & Childs, 2016). This idea has been central to many school reformers and to John Dewey - who was an American philosopher and a progressive educationalist (Boisvert, 2018). Progressivism from its start in the 1890s was a multi-faceted protest and not a unitary movement that was against one-sidedness and pedagogical narrowness (Shook, 2017).

In many countries, Dewey is viewed as the protagonist of progressive ideologue (Behuniak, 2019). Even though this is the case, he was not in all circumstances construed properly and his ideas were not always interpreted and employed the way he would have desired (Pring, 2017). Later in his career, he criticized quite severely, certain specific parts of the progressive movement (Gay, 2018).

In response to it, he was severely criticized for lacking a sense of direction and for being too academically oriented (Dunlop, Hodgson, & Stubbs, 2020). This was why Dewey never wanted to blueprint a new social order (Hachem, 2019). He believed that the prominent purpose of education should be to equip the pupils to become dynamic and participative agents in a democratic society - that is open and in the making, majorly to create their future (Newman, 2016).

This is why the method, that was central to his educational philosophy, was captured in the slogan that Dewey has become famous for, which is, "learning by doing" (Caspary, 2018). In many Western countries, after the rise of fascism and the Second World War, the *strengthening of democracy* became widely recognized as the most important aim of education (Hickman, 2017). On the school systems of Sweden, Germany, Austria, and Britain, Dewey had a prominent impact (Silalahi, 2016).

By 1946, in Sweden, Dewey has become very influential (M. Peters, 2017). Some writers of that time were greatly influenced by Dewey's ideas (Rigney, 2017). His influence rose to such an extent that those writers started voicing their opinions in favor of 'state progressivism' (Dewey, 2019). Of late, in Sweden, there rose an increased criticism against the allegedly 'soft' educational ideals of progressivism that Dewey had proposed (Keenan, 2020).

Many popular debaters and critiques of Dewey blame this progressive influence and the idea of placing excessive value on student activation and student participation with its alleged relativization of knowledge for the rapid increase in perceived problems of low achievement and lack of discipline among learners that eventually could be traced from the lack of imparting robust knowledge (Hansen, 2019).

The modern British educational system has been attacked by Michael Young who mounted a similar criticism against it (Allen & Gordon, 2017). In the past decades, the concern to provide contextual knowledge remains, and has even been accentuated despite the criticism against student participation and democratic classrooms. It is believed that only a democratic classroom will be used in life when students will step outside of their classroom and face the harsh realities which the real world has in store for them (Grammes, 2020).

For example, in chemistry, many countries today are now focussing on narrative word problems and real-world problems, because such type of questions is asked more often in the globally recognized PISA-test (Programme for International Student Assessment), and the country which performs better in PISA-test are consequently considered to have an advanced system of education.

And thus, the focus of nations is now less on imparting formula-based chemistry skills to their students which are integral to any traditional classroom chemistry. Therefore, to score well in this exam, real-life problems took precedence over teaching mere traditional classroom chemistry skills.

Verbal skills in chemistry include skill-set such as communicating, reasoning, and discussing chemistry whereas *actual doing of chemistry* includes the use of chemical and molecular formulas for manipulations and for solving equations of inorganic chemistry. A related tendency, visible today both in contemporary researches as well as in documents on chemistry curriculum, is an increased emphasis on verbal skills and less emphasis on *actual doing of chemistry*.

This development has certain theoretical underpinnings, the most prominent one being a certain specific interpretation of the distinctness between procedural knowledge and conceptual knowledge (Sikandar, 2016). This distinction has gained the status of a dichotomy that has been serving as a platform for theoretical frameworks and empirical studies (Pavlis & Gkiosos, 2017).

This paper aims to make free from confusion or ambiguity, in chemistry education, by contrasting it to the educational philosophy of John Dewey, the progression from skills in the manipulation of chemical and molecular formulas toward enhanced vehemence on verbalizations. To be more precise, the researcher will use in his analysis of the theoretical framework, the distinction that Dewey has made between the logical and psychological aspects of a subject where he will describe the knowledge of chemistry education as a product of procedural and conceptual knowledge.

It can be assistive to explicitly state the philosophy of education that was propounded by John Dewey vis-à-vis the more recent theoretical developments in the researches taking place in the field of educational theory to arrive at a refined view of the latter. The researcher attempts to examine philosophically, the assumptions inherent in most of the academicians' cognition of what constitutes understanding of chemistry.

The researcher further argues that the resulting opposition that is recognized between procedural and conceptual knowledge has led to heightened importance to verbal skills in chemistry education as opposed to skills in the manipulation of chemical and molecular formulas. Because the researcher argues that for the aim of learning chemistry this opposition is problematic, and thus he proposes emphasizing the development of operational skills, that is, the *doing of chemistry,* among the learners.

The operational aspect is inherently embedded in the existing framework. The researcher, however, argues that the operational aspect, requires more attention, for it has been increasingly neglected, over time. The researcher believes that it will allow other fellow researchers to talk more freely about the significance of computational and numerical skills by sharpening the conceptual tools that are required to discuss the underpinnings of the knowledge of chemistry.

The researcher concretizes his entire discussion taking examples of chemistry education curriculum and teaching practices prevalent in Asiatic countries, which he believes are quite interesting both from the policy as well as from an educational research perspective. As neighboring countries, the educational systems of Asiatic countries share somewhat common ideologies and values, which could be attributed to historical, cultural, and geographic reasons.

The Asiatic countries emphasize strongly on providing fair access to high-quality education to every student. In Asiatic countries, the implementation of generic competencies was developed and incorporated relatively early in the curriculum documents. In terms of generic competencies, the aim of characterizing knowledge of chemistry education was paramount. In contrast to countries in Eastern Europe and North America, applied chemistry, often referred to as *real-world chemistry*, in Asiatic countries, has been a driving force in the development and transaction of the school chemistry curriculum.

The strong emphasis on applied chemistry by Asiatic countries is reflected in the performances of students from these countries in the evaluations of TIMSS (Trends in International Mathematics and Science Study) and PISA, which are international tests. In these tests, the performance of students from the Asiatic countries is getting better on tasks that have a daily life context and relatively weak on tasks in pure chemistry.

'Pure Chemistry' should here be understood as a chemistry activity that does not explicitly take its application into consideration and is a context-independent, timeless aspect of chemistry. A concrete example would be symbolic manipulations in redox reactions. By contrast, over the years, on these evaluations, it is interesting to note that the overall results have shown a drastic difference among the Asiatic countries.

2. Education according to Dewey

Dewey stressed the connection between education and real-life, i.e., *the organic relationship between theory and practice,* and disapproved of the view of abstract knowledge as an end in itself (Gordon, 2016). Just as it was for Dewey, the main concern of school chemistry today is the practical use of chemistry. Dewey claimed that the knowledge pupils acquire in a school classroom will truly result in education and will be beneficial to them only if it addresses their pursuits, interests, and concerns (Heilbronn, Doddington, & Higham, 2018).

By this, Dewey never meant that the school shall make students spend their entire time socializing and playing instead of learning and acquiring new skills. He also never intended that teachers have no say in disciplining them and that students have all the authority to set the agenda (Caspary, 2018). Dewey never had this in mind. It was categorically argued by Dewey that by students' interest, he does not mean that they be provided whatever they wished, at any specific place and time (Taysum, 2019).

He argued that interests, in reality, have worth, and not in the accomplishment they represent (Walker-Coté, 2019). Their worth is in the leverage they afford, and not in the achievements or attitudes towards the possible experiences (Gordon & English, 2016). At a given age, to take the phenomena presented in any way, self-contained or self-explanatory, is inevitable to result in spoiling and indulgence (Hildebrand, 2018).

Whether of a child or an adult, any power, when it is taken, is indulged on its given and present level of consciousness (Frank, 2019). Toward a higher level, it affords its genuine meaning in the propulsion (Boisvert, 2018). Dewey views young pupils as born active. He believes that it is the educator's duty to realize their full potential by ensuring that their active energy is channeled appropriately (Hansen, 2012).

In order to do so, one, the teacher needs to know each student well enough so that they can direct the students in the right direction, and second, teachers shall have a thorough knowledge of the subject matter (Johnston, 2006). This calls for expertise in the subject matter as well as social and psychological understanding (Schubert, 2010). It is more demanding than merely applying the ready-made schemata (Semetsky, 2006).

A ready-made schema ignores the learners' individuality, abilities, interests, and differential backgrounds (Martin, 2003). Despite anything to the contrary, the trouble and inconvenience reflect the significance of the task (Quay & Seaman, 2013). The educational ideal for Dewey, to foster capable young learners is, despite expectations, a societal ideal where learners can participate actively and cognize critically in, and form, the society they belong to (Dewey, 1998).

Freedom that is indispensable for educational purposes is the freedom emanating from the power of self-control and not the freedom derived from external control (Hansen, 2006). On the part of the students, education should foster a spirit of criticism that requires an active undertaking and shall cultivate a habit of inquiry, which cannot be conveyed merely as truths (R. S. Peters, 2010). The slogan 'learning by doing' coined by Dewey is necessary for fostering critical thinking for the members of modern democracy and is thus considered essential and is therefore not merely a heuristic device (Hayes, 2006).

Michal Young's concept of *powerful knowledge* can help the students and can take them beyond their own experiences by allowing them to make sense of the world. To address the learners, educators need to speak to them and not at them. They shall have the cognition of their interests and thoughts, and of their lives and needs to listen to them and attend to them (Kumari & Alam, 2017).

To help the learners develop, to continually learn something new, and to reach up the academic ladder, a thorough knowledge of the subject matter is expected from the educators (Breault & Breault, 2013). They also need to have the ability to direct their students' attention to ever more difficult and abstract matters (Palmer, Bresler, & Cooper, 2001). This is illustrated by Dewey as a linear movement from the psychological to the logical aspects of the subject (Blewett, 1960).

Emphasizing the psychological aspect requires stressing learners' experiences and interests to relate to the subject matter to what the learner easily recognizes (Garrison, 2010). Emphasizing the logical aspect is instead to focus on the subject as it appears to the expert. An expert views it as an abstract corpus of knowledge pulled by its internal rules and laws.

In some respects, a subject's logical and psychological aspects, according to Dewey, is similar to Basil Bernstein's vertical and horizontal discourses. For students to be taught effectively, familiarity with both these aspects is a necessity. The teacher of chemistry must not only have the knowledge of making the chemistry constructs intelligible and interesting to the learners but also shall have great skilfulness over chemistry as an abstract corpus of knowledge.

The point that Dewey makes is that aspects such as these are inseparable and are part of a well-functioning education (Popkewitz, 2005). The psychological aspect, i.e., the child's interest, and the logical aspect, i.e., the subject matter, are the two limits that define a single process (Ashraf Alam, 2020b).

For example, just like a straight line is defined by two points, in the same way, instruction is defined by the present viewpoint of the learner and the truths and facts of studies (Kumar, Kumari, & Alam, 2018). This could be understood as: ideally, an educator begins with what interests the pupils, and not with what gives her instruction, the direction towards the goal, i.e., the 'organized bodies of truth' which is 'chemistry as abstract knowledge'.

Education thus takes place between these two defining points, the movement towards abstract subject matter from learners' experiences (Ashraf, 2020). Here, by 'Abstract', Dewey refers to a branch of knowledge that is in full control of its faculties and is strongly motivated by its principles and rules and not by real-life applications (Cochran, 2010). The phenomenon that follows is caused by some previous phenomenon, the abstract to which education is to move ahead, is a reason for wanting something done, in matters appealing to or using the intellect for their purpose of achieving or obtaining a feeling of extreme pleasure or satisfaction in thinking for the sake of thinking (Ashraf Alam, 2020a).

In chemistry education, this change of position that does not entail a change of location could be clarified by giving an example of how pupil first gains knowledge or skills to count objects capable of being perceived by their senses, and how in school-classroom, the young children are first handed over formally, with examples, that are found in their ordinary course of events in daily lives involving objects found in the everyday experiences (Malbrecht, Campbell, Chen, & Zheng, 2016).

With each passing year, classroom instructions will become more and more challenging and make a passage towards what Dewey calls the logically distinctive feature of chemistry: in the direction of chemistry as a destination in itself, free from the state of being connected to actual use or practical interests (Flew, 2010). Despite anything to the contrary, it is of great significance and value to bear in mind that these two distinctive features or elements are mutually dependent. They are two sides of the same coin, totally unlikely to divide into components or constituents in an unqualified manner (S. Alam & Raj, 2018).

The logical characteristic to be considered, as part of the discipline of chemistry moves ahead in time, order, and degree by the internal expansion, enlargement, and refinement of the discipline instead of by the requirement of applications that are concerned with actual use or practice, would be incapable of being conceived or considered, if not, except when, chemistry also is engaged in a role in human life and guided by practical experience and observation rather than being purely theoretical and abstract (Danczak, Thompson, & Overton, 2017). And the applications of chemistry, those that are guided by practical experience and observation rather than theory, in materials engineering, for example, are relying on the advancement made in the theoretical field of chemistry exploration (Zotos, Moon, & Shultz, 2020).

In school-classroom these two distinct features or elements need to go together with each other in close proximity, in order for the pupils to view education as having a meaning or purpose as well as having the necessary means, skill, know-how, and authority for them to grow more *chemistry-wise* (Priyambodo & Wulaningrum, 2017). The researcher proposes that there are resemblances between the activities of educating or instructing perspectives on chemistry and the psychological proposition of Dewey, where the pupil's curiosities, their interests, the set of facts or circumstances surround a situation or event in a learner's life.

Chemistry is concerned with actual use or practice, that is its central tenet, whereas the logical perspective imposes, involves, and implies a necessary accompaniment, and are a result of the timeless, context-independent, facets of the discipline of chemistry such as the *symbolic manipulation in chemical equations*.

As has been seen above, Dewey believed that these distinct features and elements go together in the process of education — it is imperative that chemistry education being imparted in school classroom makes a logical and causal connection to the learners' knowledge and skills that results from their direct participation in events or activities in real life and to other disciplinary domains (Saito, 2005).

This is marked by correspondence and resemblance to the cherished desires of contemporary educational theorists, who examine scientifically, study, and try to understand how chemistry education could be made such that it can furnish anticipated outcomes that is intended or that guides the learners' planned actions, answers how to make a logical or causal connection of the chemistry that is taught in the school classroom with the tasks that are concerned with actual use or practice in the real world (CHOWDHURY, 2016).

Similar to Dewey, they too wish to keep away from an educational system where the pupils merely learn by rote, the empty formulas and rules in absence of real discernment (Gilmanshina, Gilmanshin, Sagitova, & Galeeva, 2016). Despite anything to the contrary, Dewey's theoretical framework and that of the contemporary theorists of educational philosophy, does not have the same traits and characteristics and are different in many crucial respects (English, 2013).

While on the contrary, Dewey viewed the aspects that are guided by practical experience and observation rather than theoretical aspects, of chemistry, as inseparable from those aspects of chemistry that are timeless - operational aspects being one of them, and believed it to be of great significance and value, and that both needs be enclosed in the same envelope or package, in the process of teaching and learning (Lagemann, 1996). Here the researcher will argue that many of these modern educational researchers, philosophers, and theorists have a tendency or disposition to separate and act as a barrier and stand between these aspects (Dewey, 1923).

3. Chemistry Education and Educational Theory

Within the research domain of chemistry education, it is a question raised for consideration or solution that is recurred to an indefinite extent for an indefinite time, to find the most appropriate way to describe or portray the qualities or peculiarities of the knowledge of chemistry education (Akkuş & Üner, 2017). Over the course of several decades, this research problem has been, inter alia, a base for empirical studies and for the formation of a theoretical framework, to be a distinctive feature, attribute, or trait between the procedural and conceptual knowledge (Bin, Yuning, Xiaoming, & Quanzhong, 2017).

In several countries, especially the English speaking ones, everything that is included in the chemistry curriculum is influenced by this research problem (Pagliaro, 2019). Some of the research on this theme dates back to the early 1970s. Here, this kind of understanding indicates, what occurs, or is the case in the course of events or by chance, when pupils learn and engage in a large number of *fixed and specific plans* to find a solution by calculation, and detailed analysis, of a specific kind of problem in chemistry (Prins, Bulte, & Pilot, 2018). The pupils do not know and couldn't comprehend the nature or meaning of the relationship between the individual stages and the final aim of the chemistry problem (Ayyildiz & Tarhan, 2018).

The researcher does a serious examination and judgment of this kind of capacity among learners for rational thought, inference, and discrimination. He draws attention to such understanding, which could be either real or abstract, where the learners proceed in small stages and form a conceptually driven structure in the learners' schema, that can bring forth or yield plans that, without reservation or exception, get to any endpoint starting from an initial point.

The cognitive condition of understanding shall undergo and assume to become the goal by reason of learner's own ability, and the plans no more have to be established or decided beyond dispute or doubt and be linked without delay or hesitation, with no time intervention, to a unique or specific class of problems. This is the psychological result of perception, learning, and reasoning of methods employed in solving chemistry problems, where procedures are the series of prescriptions depending on each other as if linked together to influence and control symbols.

From another viewpoint, the expression *conceptual knowledge* is accounted as a psychological result of perception, learning, and reasoning that is complete in extent or degree of connectedness that can be viewed as a logically or causally connected intricate web of knowledge, an interconnected system in which links are as significant and valuable as the classified chunks of information.

The state of connectedness is so common that all the knowledge acquired through study, experience, and instruction is associated with a certain specific network of interconnected individual facts and logical statements. In order to describe or portray the character or the qualities or peculiarities of this kind of knowledge, the phrase *conceptual structure* is oftentimes used.

The researcher describes and emphasizes the combination of circumstances at a given time where the learner not only puts into service, applying to or characterized by, the concepts in chemistry but also has an understanding of nature, the meaning, the quality, or the magnitude of the whole concept. Building on the above ideas, the researcher has developed a conceptual framework for discussion in which reasons are advanced for and against chemistry propositions and argumentations. Researcher further notes that none of these are resulting from one's intentions for the act of describing distinctive characteristics or essential features of the endowment of capacity to reason.

Researcher claims, basing his logic grounded on his own previously conducted empirical researches, stating that learning by rote memorization is a prominent element in support of learning and achievement difficulties (A Alam, 2020). Discrimination between them, i.e., between *imaginative* and *mimetic*, where the latter is linked to learning by rote memorization, as different and distinct is made between the two as distinguishable chemic reasoning in order to specify as a condition or requirement and communicate the outcomes of his empirical research (A. Alam, Kumari, & Alam, 2018).

The researcher goes back to the memory lane and recalls a complete reaction to a specific chemistry problem, where a pupil who memorized by heart each step of the solution and consequently fails to explicate the significance of any of the steps she used therein (S. Alam & Raj, 2017). It can also be called an elaborate and systematic plan of action where a student recalls a distinct statement or algorithm that solves a problem or explains how to solve the problem, having the same or nearly the same characteristics or correspondence to the statement that represents it in words of procedural skilfulness by virtue of possessing special knowledge (S. Alam & Kumari, 2017).

Taking into consideration the cognitive processes of acquiring skills and knowledge with regards to *committal chains* and tools such as '*learning number of fixed and specific plans'*, the researcher, by contrast, draws attention to the significance of creative thinking. This occurs or becomes the case in the course of events or by chance when a pupil brings into existence original reasoning of a kind not seen before, the sequence gives a new life or energy to a disremembered sequence, in which there are logical argumentations that back the selection of the highly important or an integral part of a strategy or plan of action and arguments that are grounded in the chemical properties of the chemical constituents involved.

The statement here that makes something comprehensible by describing the relevant structure, operation or circumstances, etc., of the conceptual knowledge, is being connected either logically, causally or by shared characteristics to the linked web of knowledge - the network in which associated connections are as good in quality that thrusts itself into attention as the discrete pieces of information, and understanding of relationship is a desegregated understanding of the relationship between case-by-case and item-by-item phases and the conclusively intended goal of an exercise.

The most important elemental dissimilarity between imitative and creative reasoning is that in the latter case the explanation and solution to the chemistry problem are created, while on the contrary, in the former, the statement that solves a chemistry problem or explains how to solve the problem follows a known path or is immediate through recollection. Directing the attention on the capacity for rational thought, inference, or discrimination of knowledge, and on the thinking, the researcher asseverates that the common goal is to record the narrative description for the disagreement or argumentation between learning by heart is simply free from a real understanding.

Being cognizant and aware of the fact or information, and possessing knowledge, about how to apply in a manner that is consistent with its purpose and design, is effective learning. As both the educators as well as the researchers are in agreement that learning empty formulas of physical or organic chemistry in absence of making known the message or idea that is intended, expressed or signified, is not an educational purpose that is worthy of being recommended or suggested. Theorists and researchers, thence are attempting to create by training and teaching methods for ameliorating the conceptual knowledge of learners and making small or less significant, the procedural knowledge (Granger, 2016).

Several studies are in contradiction with this trend and direct the attention to the positive results of imaginative reasoning, procedural understanding, and instrumental understanding (Gonon, 2009). As an example, several researchers have argued that research in the pedagogy of chemistry education should emphasize concentration of attention and energy on the procedural knowledge of the learners basing their research on these three points: (1) Insufficient attention is given to the expansion, enlargement or refinement of learners' procedural knowledge; (2) It can be explicated that the current procedural knowledge characterizations are grounded on assumptions that are limited in range and scope of the understanding of procedures; and (3) Procedural knowledge that is reconceptualized would have far-reaching consequences on both research and practice, to remedy these assumptions.

The researcher further notes that in the 1980s, the use of process knowledge followed by the mutual dealings or connections or communications among procedural and conceptual knowledge was an area that was being discussed for research in developmental psychology, and has been extensively studied in range, scope, and quantity within the sub-domains of cognitive psychology (Hendley, 1989). The researcher is mid-way writing a critical paper where he strongly affirms the distinguishing difference between procedural and conceptual discernment emphasizing that it is tampered with the purpose of deception, branching repeatedly into two opposed parts or subclasses in chemistry education (Fairfield, 2009).

Researcher maintains that the understanding which is characterized by concepts or their formation and the quality of being adequately well qualified both physically and intellectually with regards to procedural competencies cannot be weighed as distinct entities, given that the procedure of improving by expanding, enlarging, refining and forming or establishing, are conceptual and contributes to the understanding of processed chemic objects (Weiqing, 2018). Besides, process skill also has an important conceptual component having a great significance and value because the procedures are such that it must be updated regularly, altered or revised by rephrasing or by adding or deleting and intensified in value or beauty or quality, including those that function as an anticipated outcome that is intended or that guides the planned actions, like the ones that are automatically operated (Markic & Childs, 2016).

The classification into two opposed parts or subclasses that is usually thought of between procedural and conceptual understanding taking into account the capacity for rational thought, inference or discrimination, is distinctly detrimental in organic chemistry, for physical chemistry has undergone a change to become a domain that is controlled and ruled by the superior symbolic manipulations, where the conceptual understanding is mostly non-existent (Shekhovtsova, 2018). On the grounds of several physical chemistry study projects undertaken globally by different investigators, the researchers argue that the physical chemistry examples of the co-emergence of procedural (or technical) and conceptual components and of the interaction between them, suggests that the expressions in physical chemistry are not very detailed, instead, the focus is on the trend where the view that procedural is inferior to conceptual, is hugely prominent (WU & LOU, 2017).

The researcher, in the subsequent sections of this paper, tries to identify the reasons for this dichotomy and outlines what is predominantly called the operational aspect of chemistry that was lost in this process.

4. The Goal of Teaching Chemistry

Today, eminent educational theorists believe, like Dewey, that pupils should not earn those chemistry constructs that are specific to the school curriculum and that which will not be used anywhere else outside in the real world (Devetak, 2020). Rather, the chemistry that is related to their day-to-day activities, which can help them manage and make sense of other areas of their lives, shall be part of the school chemistry curriculum (LEE, SHARIF, & RAHIM, 2018). School chemistry is heavily criticized for being boring and lacking in interest causing mental weariness and focussing too much on context-free chemistry problems (Becker, 2018). This allows students to only acquire surface knowledge, and thus these techniques can then be used only in the chemistry classrooms and are of no use in the real-world (Hugerat, 2020).

In chemistry classes, a great deal of time is invested in engaging in the rehearsal of ascertainment of procedural chemic problems, which is based primarily on surmise rather than adequate evidence, to equip students with abilities to quickly and reliably acquire the coping mechanisms for the several tasks which they will come across at a later time in their life span (Goes, Fernandez, & Eilks, 2020). Despite anything to the contrary, there are dubiousness and uncertainties as to whether these procedural chemic problems, in reality, bring acclivity to the understanding of the principles of chemistry that is marked by greater depth of thinking, or contrarily the extensive and all-encompassing application of procedural problems will hinder the achievement of the very goal of learning chemistry (Taber, 2016).

As delineated above, the all-encompassing application of procedural chemic problems only leads to the development of procedural knowledge that concerns with or comprehends only with what is apparent or obvious and not deeply penetrates either emotionally or intellectually (Mack & Towns, 2016). This is, for most of the times, believed to happen when the educator paves the way for their pupils to come up with an answer to the chemistry problem with the assistance of a pre-defined procedure, and the pupils afterward are made to figure out the solutions of a series of chemistry problems making use of the same algorithm (Overton, 2019).

This pedagogy is potently critiqued by many chemists and researchers on the grounds of its real or perceived flaws (Cooper & Stowe, 2018). There are extensive worries appertaining to the idea that pupils do not acquire enough chemistry understanding and competence (Liying, 2018). This state of difficulty is leastways partly connected either logically or causally to the process of teaching where learning is procedure-based (Cho & Baek, 2019). Dewey attempted to refrain from *Reasoning-by-Imitation* by emphasizing the significance and essentiality of *psychologizing* the academic discipline, making it to arouse and hold the attention of the pupils by making a logical and causal connection of it to their lives outside the classroom which they found in the ordinary course of events, and then bit by bit advancing in the path of more *abstract knowledge* (Dewey, 2011).

Thinking abstractly is certainly the ultimate aim for the chemistry teachers, chemists, and educational researchers of modern times that we have retrospected and examined above, but still, they do not share Dewey's discernment and perceptiveness of *abstract thinking* (Saltmarsh, 2008). Solving problems *chemistry-wise* is a competence that carries out or participates in an activity involving chemistry, as is done by a researcher, who shows interest, curiosity, fascination, and concern towards experimentations, refutations, and proofs, not as means to achieve practical ends but as ends in themselves (Garrison, Neubert, & Reich, 2015).

Handy everyday applications are significant in individuals' regular day to day existence, just as in the professional lives of business analysts, architects, and physicists, to give some examples, yet it isn't the subject matter and thrust area of higher chemistry (Brooke & Frazer, 2013). As described and stressed by Dewey, only one out of every odd student should turn into an expert in a subject area, yet it is excessively significant that their objective is constantly set high (in each subject), with the goal that the learners are pushed to perpetually complicated and troublesome tasks, to build their reasoning abilities, and critical thinking skills so that they achieve higher ends than they might have anticipated (Dewey, 1923; Novak, 1994).

Today, notwithstanding, there is a developing propensity to comprehend theoretical reasoning, the profound chemistry comprehension, is that which is communicated in contentions, arguments, modeling, and contextualization (ZHU, FENG, CHEN, & TIAN, 2018). This inclination is likewise obvious in the curricula of numerous nations today, where chemistry understanding and knowledge of chemistry education is, as a matter of first importance, attached to verbal abilities: to be capable, in words, to clarify why one chemistry experimentation is desirable over another (ZHAO, LI, HONG, & ZHU, 2017).

For example, in the current Swedish chemistry curriculum, the demands for knowledge depend on conventional skills, for example, the capacity to describe the constructs of chemistry and to perform chemistry communications in different settings, as opposed to the ability and capacity to compute and reach at the correct results to chemistry problems specifically pertaining to activation energy and Arrhenius equation (ZHANG, ZHAO, & ZHANG, 2016). The discourse material to the Swedish national educational plan underscores that students ought to figure out how to utilize metacognitive reflections so as to verbally process, and search for alternative solutions to chemistry problems (like calculation of the total change in the Gibbs free energy) as well as discuss, examine, assess, and evaluate chemistry solutions, solution techniques, methodologies, strategies adopted, and results obtained (Kousa, Kavonius, & Aksela, 2018).

This is in contrast to the Indian curricula where the significance of making pupils learn numerical and computational abilities is emphasized by referring to certain explicitly specific areas of chemistry that the pupils are expected to ace, so as to oversee significant pragmatic and day-to-day affairs, and to become capable citizens. Also, the Indian curricula endorse that the pupils ought to learn chemistry algorithms for solving chemic problems on chemical bonds, oxidation, reduction, dissociation, acid-base neutralization, and molecular rearrangements, in procedural ways. At the same time, there are signs that the pupils' operational aptitudes are compromised. Indian pupils appear to have pretty vulnerable and weak aptitudes in chemistry contrasted with their Singaporean counterparts.

In Australia, the physical chemistry problems like chemical thermodynamics, chemical kinetics, electrochemistry, quantum chemistry, statistical mechanics, and spectroscopy, that are laid out in the educational and instructive materials for upper secondary school have become simple and less mind-boggling contrasted with the ones that were there in the 1960s, 1970s, and 1980s (CHEN, QIU, JIANG, & ZHU, 2017). Moreover, an error in what is viewed as significant knowledge of chemistry education has developed between the Australian secondary school and the colleges/universities therein (Gibbons, Villafañe, Stains, Murphy, & Raker, 2018).

At the college and university level, aptitudes and skills that are used routinely in number-crunching and arithmetical calculations in several topics of chemistry including medicinal chemistry and pharmaceutical chemistry and are viewed as completely fundamental when learning advanced chemistry, though, in the educational plans of secondary school chemistry, the focus lies on problem-solving skills and critical thinking abilities and how pupils understand chemistry constructs and get ideas, as opposed to repeatedly rehearsing the skills to solve typical chemic problems such as the numerical computation of structures, composition, mechanisms, and chemical reaction of carbon compounds (XIE & LI, 2017).

This gets problematic and quite risky in those situations where the computational complexity and multifaceted nature of chemistry activities at the university level are excessively tough and *over-the-degree-of-unpredictability* because the pupils are accustomed to the school-level chemistry (Aleksandrovna, 2018). Consequent to it, at the university level, numerous students experience major issues when they start studying chemistry, and initial difficulties in solving these chemistry problems, specifically on quantum mechanics and chemo-informatics, may prompt prolonged unfavorable outcomes and fruitless and unsuccessful studies leading to failing in accomplishment of intended results or even could be a major reason for learners to quit their studies in chemistry (Orgill, York, & MacKellar, 2019).

It appears that these issues are not restricted only to Asiatic countries (Winston, 2019). There are comparable issues and problems in different nations as well, for example in African and some European countries (Agustian & Seery, 2017). Here the researcher contends that an expanded spotlight on operational aptitudes in secondary schools, not least in the national curriculum of chemistry, is vital so as to facilitate and encourage the transition from secondary school to college-level chemistry.

Understanding Chemistry

To comprehend better the advancement from computational aptitudes toward verbalizations, we need to look even more carefully at how chemic algorithms are perceived (Blonder & Mamlok-Naaman, 2019). A typical view is that the applications of algorithms that help determine Avogadro Constant or Molar Concentration don't enhance chemistry understanding (Rautiainen, 2016). The benefit of applying and making use of *algorithms* is to make *solving chemistry problems* simpler for the learners and to arrive at the correct conclusion(s), but the ability and capacity to apply an algorithm for chemistry calculation isn't a sign of any deeper and more profound comprehension of the principles and concepts of chemistry (Wei & Liu, 2018).

The motivation behind applying an algorithm to efficiently and accurately solve a chemistry problem but not for actual learning is that it is intentionally designed to abstain learners from *meaning-making* (Stojanovska, Mijic, & Petrusevski, 2020). The use of algorithms for accurate computation of substance and mixtures is oftentimes viewed as quite mechanical and it is also contended that in such cases only recklessness can prompt a student to commit an error (Kinnunen, Lampiselkä, Meisalo, & Malmi, 2016). Indeed, imitative reasoning, the use of rules and algorithms, is occasionally thought of as something contrary to creative reasoning (Wheeler, Maeng, & Whitworth, 2017).

The part of innovativeness and creativity that is accentuated in this structural framework isn't a *virtuoso* or *exceptional and uncommon novelty*, yet the computation of solutions of chemistry-tasks that can be unassuming and modest, however, are unique to the individual who develops them (Lawrie & Southam, 2018). Hence, creative imagination is contrary to imitation. On the off chance, if imitative reasoning, i.e., the use of algorithm or rules is taken as contrary to attractively desirable creative reasoning, teachers may get fatigued and jaded of inculcating numerical ability among students for the most part (LIU, JIANG, & LIN, 2017).

In the event that if the most significant thing is the manner of thinking, i.e., the thought process behind the chemistry calculations, as opposed to the chemistry calculations itself, then verbal clarifications and verbal explanations are very much expected from the learners to show whether they truly understood and comprehended the chemistry tasks or completely associated with problems that they finished (Fei, Dong, & Jianqing, 2017).

The calculations and estimations could, all things considered, shall be the consequence of just precisely applying the algorithms or the rules of computation (Fahmy, 2017). In this methodology, the endeavors of a learner who applies an algorithm to tackle a chemistry task and can check whether or not she, based on the algorithm, has obtained the correct solution to the problem, is compared with the endeavors of the learner who copies the solution to the chemistry problem from another learner and has no clue about what algorithm was utilized, and teachers couldn't understand how to ensure the appropriateness or correctness of the response/solution (Koeper, Shapter, North, & Houston, 2020).

What is the explanation behind the negative origination of the utilization of algorithms for chemistry problem solving, and what is the nature of possibility or the idea that the knowledge of chemistry education ought to be communicated verbally? In the accompanying paragraphs, I will examine *understanding* instead of *knowledge*, since we need to concentrate on the procedure taken to underlie knowledge of chemistry education, as opposed to the displayed ability/competence. We can't help thinking what are the philosophical presumptions made about comprehension and understanding of chemistry problems and its solution.

A typical dualistic approach is undertaken, where comprehension and understanding are taken to be a psychological and mental procedure, a procedure of which the chemistry calculation is the outcome/result. The outcome supposedly is dependent upon the genuine comprehension, which is covered up—simply like the mind-body dualism, the bodily expression or the bodily articulation of the feeling is determined by conditions or circumstances that follow:

what we could do is to shroud our emotions or force a smile, even when we are pitiful.

We cannot trust the outward appearances to uncover an individual's actual emotions, as we cannot trust the chemistry calculations done on a piece of paper to uncover the mental and psychological processes of the student that lies beneath them. Consequently, we cannot know how the pupils finished up with the problems related to fields like photochemistry, phytochemistry, polymer chemistry, supramolecular chemistry that s/he has recorded in their notebook. This perspective of the performed figuring and calculations is vacant and hollow in itself, combined with an idea of two particular sorts of reasoning, one that is desirable and alluring (creative) and the other which is not (imitative), brings about a *doubt* around the chemistry solutions and operations used therein by pupils who have recorded it in their notebook as likely expressions of just remembering or rote memorizing the empty rules or procedures.

Consequent to it, we need something different, something notwithstanding a customary chemic problem to ensure that the chemic computations originate from genuine comprehension—and that finally what we get is a verbalized record. That comprehensive understanding is fundamentally thought of as a mental and psychological phenomenon and is showcased by the significance consociated to cerebrum action, in studies investigating how the varied methods and techniques of teaching influence the brain's cognitive processes (Crimmins & Midkiff, 2017).

For example, I once conducted a mini-research study wherein a group of learners was given chemistry problems to solve, making use of only the given algorithms and rules to solve chemistry problems, through reasoning by imitation, and another group tackled exactly the same set of chemistry tasks utilizing what is commonly described and portrayed as innovative and critical thinking. In the wake of working with the chemistry problems for seven days, their cranial activity was checked and monitored extensively and the solutions to the chemistry problems were compared between the two groups.

One issue with pointedly isolating understanding as cranial activity and the culmination of a chemistry problem-solving task as the consequence of this comprehension is that the gap between the test circumstance and real-life problems broadens. This gets evident in this research that is concerned accurately and definitely with making chemistry relevant and applicable to real-life worldly situations. One methodology to arrive at this point, it is contended, is by making sensible and realistic chemistry word problems, that are narrative in nature, for the pupils to fathom, and similar to the one undermentioned:

A 6.0 L sample at 25°C and 2.00 atm of pressure contain 0.5 moles of a gas. If an additional 0.25 mole of gas at the same pressure and temperature are added, what is the final total volume of the gas? (right answer: V_f = 9 L)

A sensible component of this chemistry problem is that the pupils need to make sense of Avogadro's number. Avogadro's law was originally proposed by Amedeo Avogadro and in 1811, he hypothesized two samples of an ideal gas with the same volume and at the same pressure and temperature contained the same number of molecules and that Avogadro's law is also called Avogadro's principle or Avogadro's hypothesis. Also, like the other ideal gas laws, Avogadro's law only approximates the behavior of real gases. Under conditions of high temperature or pressure, the law is inaccurate. The relation works best for gases held at low pressure and ordinary temperatures. Also, smaller gas particles—helium, hydrogen, and nitrogen—yield better results than larger molecules, which are more likely to interact with each other.

In this chemistry problem, which was used to assess the learners' thinking and reasoning competency, full marks shall be given to those learners who will demonstrate and model the chemistry problem effectively and correctly, regardless of whether they make calculation mistakes and consequently come up with a wrong answer. In one classroom experiment where a similar task was given to students, the learners' test outcomes improved subsequent to practicing and rehearsing with word problems that were realistic and narrative in nature.

It was observed and concluded that word problems positively affect learners' problem-solving skills and critical thinking abilities. However, it is evident that *critical thinking expertise* here alludes only to the capacity to model the chemistry task and not the capacity to finish it with the correct solution. Envision a genuine real-life circumstance, where a person who has a sound conceptual knowledge of chemistry and oftentimes commits calculation errors thereby coming up with wrong answers.

To the industry owners, relying upon this person would not get the job done for the fact that she could only think effectively, but couldn't get her sums right. Truth be told, in most genuine real-life circumstances, regardless of whether we have to pay the income-tax or to make sense of what medical drug dose to take, we have to come up with the right answer to abstain from suffering negative outcomes. In the most widely recognized sense of critical thinking and problem-solving, the learners who come up with inappropriate or wrong outcome is said to have failed to solve the chemistry task.

Mastery over theoretical chemistry by pupils forms the base for all types of applied chemistry and is clearly delineated in the chemistry cycle of applied chemistry. Nonetheless, in countries where the language of communication is English and also in Nordic nations, to a large extent, it has somewhat been misjudged and misunderstood that applied chemistry can be viewed as an alternative option to pure chemistry.

Again, it tends to be helpful for us to remember Dewey's recommendation to not separate the mental (psychological) and the logical dimensions of any educational discipline, i.e., for effectively coming up with a solution to any task, we need critical thinking skills, sensitivity towards the context of the problem, reasoning skills, thinking competencies in the language of the discipline, situational understanding, and the capacity to perform calculations that would be required (Caspary, 2018).

In chemistry problems, specifically in organometallic chemistry, bioinorganic chemistry, and cluster chemistry, it is found that mere learners' critical thinking skills and reasoning capacity are not sufficient to arrive at the solution to the chemistry problem at hand, they additionally should be capable and efficient enough to perform all the problem-solving in rich chemistry (Copriady, Zulnaidi, & Alimin, 2018). For Dewey, this continual and persistent demand is associated with his outright rejection and dismissal of dualism (Reich, 2008).

Also for him, the abstract or general idea inferred and derived from intelligence is simply a mental phenomenon and nothing else (Seigfried, 2010). The possibility that we could know whether somebody is a profound thinker through considering in detail and subjecting to analysis their brain is consequently farcical and derisory to him: thinking and analyzing is internally linked with the brain's expressed feelings, to how we supervise and oversee our day-to-day practical activities.

To recommend that critical thinking aptitude and problem-solving skills could be assessed independently and autonomously of whether the skill and expertise tackle the chemistry problem in actuality, for which it was set out to solve, would neither sound good nor will make sense.

Learning by Doing: Operational Skill

The researcher contends that the distinctness among procedural and theoretical/conceptual knowledge has prompted a polarity where operational skill and ability has fallen steadily over the years. Considering this hypothetical speculation, which follows from Dewey's educational philosophy, that the various distinct aspects of chemistry need to go connected at the hip. He discovered and found it especially critical and particularly important to underline operational skill and expertise, which joins procedural and conceptual components and elements.

The operational dimension of chemistry is a methodological perspective that the pupils learn by participating and engaging in chemistry problems, for example performing computations pertaining to cosmochemistry by studying the chemical composition of matter in the universe and the processes that led to those compositions, solving equations on supramolecular chemistry where the focus is on the chemical systems made up of a discrete number of assembled molecular subunits or components, controlling and manipulating symbols in green chemistry and encouraging the design of products and processes that minimize the use and generation of hazardous substances, and demonstrating proof of chemistry theorems.

It is anything but a matter of precisely and mechanically applying formulae, and it need not be identified with a certain specific cognitive procedure, yet is part of practical training and rehearsing that the chemist needs to ace so as to build up their chemistry instinct and view important and relevant associations and connections where others would not. Regardless of whether acing the operational angle requires practice, it involves a context-free or setting-free timeless dimension (and is hence *conceptually abstracted* in Dewey's sense).

The ultimate way to operational aptitude and skill lies in acing the chemistry symbolism and the principles that have been worked out through hundreds of years of advancements in chemistry education and research. A case at hand pertaining to it would be to comprehend the correct method to utilize an algorithm at the right place. One methodological way of understanding the operational part of chemistry is to depict it as the representative idea of the symbolic nature of chemistry, as in the way chemistry has been sensed and comprehended for the past several centuries.

In this view, chemistry isn't something we initially learn and afterward do, rather chemistry is something that we have to learn by doing. A symbolism or imagery isn't simply an arrangement or system of notation in the typographical or linguistically semantic sense, rather is associated and deeply connected with the chemistry problem itself. It is the operational aspect of a symbol, its functional capacity in the analytics of chemical equations, its job in the manipulative control, and transformative change of articulations and expressions, which comprise the symbols of chemistry (Erduran & Kaya, 2019).

Dewey's legitimate and logical element of education can thus be recognized as the representative origination or symbolic conception of chemistry: to champion the logical aspect and to improve the intelligent angle is to acquire mastery over symbolic chemistry. The researcher contends that in the conceptual framework for clarifying and explaining *chemistry understanding* and knowledge of chemistry education, through conceptual and procedural knowledge, the various dimensions of knowledge of chemistry education are frequently treated as unmistakably delineated, clearly demarcated, and separate sets of aptitudes and skills.

This prompts a disregard of the operational dimension of chemistry, which could be said to fall into the two broad categories. Especially when the procedural and the conceptual are seen as contrary to each other, there is almost no room left for conceptualizing, evaluating, or assessing the reflective use of algorithms and rules. Procedural knowledge need not exclusively involve rote learning. In learning a strategically developed method for solving a chemistry task, the pupils learn and figure out to ace an analytical problem in a way unique to the discipline of chemistry.

Be that as it may, the ability to effectively utilize the chemistry notations, symbols, and rules requires a great deal of training and practice, as opposed to the *novelty*, *originality*, and *innovation* that is associated with conceptual knowledge. In this sense, it consolidates parts of both the conceptual as well as the procedural and resolves the obvious restrictive opposition between them. To put it plainly, the researcher proposes to feature the genuine doing of chemistry that is oftentimes referred to as operational skill or operational aptitude.

Following it, the researcher consequently contends that the polarity between procedural expertise and conceptual comprehension is completely misplaced or lost since procedures and methodology are conceptual in nature. The danger underlying teaching to pupils, thoughtless and mindless principles and rules, is by all accounts one of the most pressing reasons for why the distinction conceptual/procedural has transformed into something of a dichotomous polarity, and we understand the significance of staying away from this sort of learning where the emphasis is on rote memorization.

In any case, it is essential to bring up to the forefront that just memorizing the procedures or mirroring the solutions without comprehension may not appropriately be called procedural knowledge by any stretch of the imagination, but simply a failed system of education. Be that as it may, rehearsing rules and procedures is often an important step in figuring out how to utilize them operationally and with comprehension, and should hence not be compared with mere copying or deriving from the original, and is predominantly viewed as irrelevant for learning chemistry since acquiring knowledge of chemistry education is subject to the pragmatic and practical command over symbols, procedures, and techniques.

Knowledge of chemistry education picked up by methods for analogies, visualizations, representations, and verbal clarifications are significant methods for creating a setting in which the pupils find themselves at home in the material, however verbal clarifications, often distinguishingly identified as proof of conceptual knowledge, can't supplant the emblematic computations and symbolic calculations that the learner needs to ace so as to solve a chemistry task. Researchers and chemistry teachers accordingly need to emphasize operational ability, to capture the significance of numerical and computational aptitudes for knowledge of chemistry education, and not as mindless and careless rule-following and principle-following, but as a thoughtful, insightful, and utility-based application of skills and abilities that are often necessary and quite fundamental for the cognition and understanding of derived solutions – the chemic way.

Conclusion

The researcher contends that the current structural framework for explaining and clarifying knowledge of chemistry education in terms of conceptual and procedural knowledge is regularly interpreted and carefully deciphered as a dichotomy between the two dimensions that are fundamental for education and instruction: useful verbal clarifications and practical modeling (Dewey's psychological perspective), and the operational, emblematically symbolic aspects and viewpoints that are liberated from the contextual setting (Dewey's logical perspective), on the other. Partly because of how conceptual and procedural knowledge are characterized, numerical and computational aptitudes/skills have gotten less significant in chemistry education, and meta-chemistry, communicative skills are viewed as increasingly significant, as epitomizing and embodying what is thoughtfully believed of as *genuine and real knowledge* of chemistry education.

There are signs that learners' numerical and computational aptitudes and skills have suffered poorly over the years. There are numerous causes behind these turns of events. The accentuation on practically useful employments of chemistry and 'every-day/real-world chemistry', at the expense of emphasis on the acquisition of chemic aptitudes could be one of them.

The nations that accentuate and draw attention to chemistry understanding that is required in daily life (contextual) will in general be less worried about numerical and computational abilities and skills that are required in chemic problems. Consequently, the researcher proposes a novel approach to the existing research framework, with more accentuation put on operational abilities and skills.

There is thus a dire need to incorporate chemistry as a practical activity that the pupils need to engage and enthusiastically take part in, as it is concerned with the representative, symbolic, setting-free, and context-free nature of chemistry. It is indeed a call to resuscitate the Deweyan trademark slogan of *learning by doing* in chemistry education.

References

Agustian, H. Y., & Seery, M. K. (2017). Reasserting the role of pre-laboratory activities in chemistry education: a proposed framework for their design. *Chemistry Education Research and Practice, 18*(4), 518-532.

Akkuş, H., & Üner, S. (2017). The Effect of Microteaching On Pre-Service Chemistry Teachers' Teaching Experiences. *Cukurova University Faculty of Education Journal, 46*(1).

Alam, A. (2020a). Pedagogy of Calculus in India: An Empirical Investigation. *Alam, A.(2020). Pedagogy of Calculus in India: An Empirical Investigation. Periódico Tchê Química, 17*(34), 164-180.

Alam, A. (2020b). Possibilities and Challenges of Compounding Artificial Intelligence in India's Educational Landscape. *Alam, A.(2020). International Journal of Advanced Science and Technology, 29*(5), 5077-5094.

Alam, A. (2020c). Test of Knowledge of Elementary Vectors Concepts (TKEVC) among First-Semester Bachelor of Engineering and Technology Students. *Periódico Tchê Química*, *17*(35), 477-494.

Alam, A. (2020d). Challenges and Possibilities in Teaching and Learning of Calculus: A Case Study of India. *Journal for the Education of Gifted Young Scientists, 8*(1), 407-433.

Alam, A., Kumari, M., & Alam, S. (2018). Seventh Pay Revision Vis-à-Vis Higher Education in India. *Indian Journal of Social Research, 59*(5), 719-733.

Alam, S., & Kumari, M. (2017). Tribal Heritage Conservation in Jharkhand from an Anthropological Viewpoint. *Indian Journal of Social Research, 58*, 913-924.

Alam, S., & Raj, A. (2017). The Academic Journey of Witchcraft Studies in India. *Man in India, 97*, 123-138.

Alam, S., & Raj, A. (2018). Witchcraft and Witch-Hunting in India: An Assessment. *Emerging Challenges of Violence Against Women, Odisha State Women Commission, Bhubaneswar, India*, 21-25.

Aleksandrovna, V. S. (2018). Theory and practice of updating the content of education in chemistry and teaching methods, in view of modern science and technology achievements. *Revista Espacios Venesuela Scopus, 39*(05), 32-38.

Allen, S., & Gordon, P. (2017). *How Children Learn-Book 4: From Steiner to Dewey-Thinking on Special Educational Needs and Inclusion* (Vol. 4): Andrews UK Limited.

Apotheker, J. (2019). *Teaching Chemistry: A Course Book*: Walter de Gruyter GmbH & Co KG.

Ayyildiz, Y., & Tarhan, L. (2018). Problem-based learning in teaching chemistry: enthalpy changes in systems. *Research in Science & Technological Education, 36*(1), 35-54.

Becker, H.-J. (2018). COMMERCIALS AS PART OF DAILY LIFE SITUATIONS-IMPULSES FOR CHEMISTRY TEACHING AND FOR METHODICAL REFLECTIONS OF MS-COURSE STUDENTS OF THE HO CHI MINH CITY UNIVERSITY OF EDUCATION/DEPARTMENT CHEMISTRY IN NOV./DEC. 2018. *EDUCATION*(PART 1).

Behuniak, J. (2019). *John Dewey and Confucian Thought: Experiments in Intra-cultural Philosophy, Volume Two*: SUNY Press.

Bin, C., Yuning, M., Xiaoming, S., & Quanzhong, W. (2017). Exploration of Teaching Reform of Inorganic Chemistry Experiment in Local Universities under the Background of Transformation of Education. *Modern Chemical Research*(4), 30.

Blewett, J. E. (1960). *John Dewey: his thought and influence*: Fordham University Press New York.

Blonder, R., & Mamlok-Naaman, R. (2019). Teaching chemistry through contemporary research versus using a historical approach. *Chemistry Teacher International, 1*(ahead-of-print).

Boisvert, R. (2018). *Dewey's Metaphysics: Form and Being in the Philosophy of John Dewey*: Fordham Univ Press.

Breault, D. A., & Breault, R. (2013). *Experiencing Dewey: Insights for today's classrooms*: Routledge.

Brooke, C., & Frazer, E. (2013). *Ideas of education: Philosophy and politics from Plato to Dewey*: Routledge.

Caspary, W. R. (2018). *Dewey on democracy*: Cornell University Press.

CHEN, X.-y., QIU, Z.-g., JIANG, Y., & ZHU, Y.-w. (2017). The Establishment and Application of the Principle of Combining "Theory with Practice" in the Teaching of "Engineering Chemistry". *Anhui Chemical Industry*(6), 46.

Cho, J., & Baek, W. (2019). Identifying Factors Affecting the Quality of Teaching in Basic Science Education: Physics, Biological Sciences, Mathematics, and Chemistry. *Sustainability, 11*(14), 3958.

CHOWDHURY, M. A. (2016). Gifted education in science and chemistry: Perspectives and insights into teaching, pedagogies, assessments, and psychosocial skills development. *Journal for the Education of Gifted Young Scientists, 4*(1), 53-66.

Cochran, M. E. (2010). *The Cambridge Companion to Dewey*: Cambridge University Press.

Cooper, M. M., & Stowe, R. L. (2018). Chemistry education research—From personal empiricism to evidence, theory, and informed practice. *Chemical Reviews, 118*(12), 6053-6087.

Copriady, J., Zulnaidi, H., & Alimin, M. (2018). In-Service Training for Chemistry Teachers' Proficiency: The Intermediary Effect of Collaboration Based on Teaching Experience. *International Journal of Instruction, 11*(4), 749-760.

Crimmins, M. T., & Midkiff, B. (2017). High structure active learning pedagogy for the teaching of organic chemistry: Assessing the impact on academic outcomes. *Journal of Chemical Education, 94*(4), 429-438.

Danczak, S., Thompson, C., & Overton, T. (2017). 'What does the term Critical Thinking mean to you?'A qualitative analysis of chemistry undergraduate, teaching staff, and employers' views of critical thinking. *Chemistry Education Research and Practice, 18*(3), 420-434.

Devetak, I. (2020). Michael K. Seery and Claire McDonnell (Eds.), Teaching chemistry in higher education, Creathach Press, 2019; 452 pp.; ISBN: 978-09-928-2331-3. *Center for Educational Policy Studies Journal, 10*(2), 175-179.

Dewey, J. (1923). *Democracy and education: An introduction to the philosophy of education*: Macmillan.

Dewey, J. (1998). *The essential Dewey: Pragmatism, education, democracy* (Vol. 1): Indiana University Press.

Dewey, J. (2011). *The sources of a science of education*: Read Books Ltd.

Dewey, J. (2019). John Dewey. *North American Scholars of Comparative Education: Examining the Work and Influence of Notable 20th Century Comparativists*.

Dunlop, L., Hodgson, A., & Stubbs, J. E. (2020). Building capabilities in chemistry education: happiness and discomfort through philosophical dialogue in chemistry. *Chemistry Education Research and Practice, 21*(1), 438-451.

English, A. R. (2013). *Discontinuity in Learning: Dewey, Herbart, and education as transformation*: Cambridge University Press.

Erduran, S., & Kaya, E. (2019). *Transforming Teacher Education Through the Epistemic Core of Chemistry*: Springer.

Fahmy, A. F. M. (2017). The systemic approach to teaching and learning chemistry [SATLC]: a 20-years review. *African Journal of Chemical Education, 7*(3), 2-44.

Fairfield, P. (2009). *Education after Dewey*: Bloomsbury Publishing.

Fei, X., Dong, F., & Jianqing, T. (2017). Exploration on the Reform of Comprehensive Chemistry Experiment Teaching in Local Normal Universities. *Experiment Science and Technology*, 06.

Flew, A. (2010). Democracy and education *John Dewey reconsidered (International Library of the Philosophy of Education Volume 19)* (pp. 56-72): Routledge.

Frank, J. (2019). *Teaching in the Now: John Dewey on the Educational Present*: Purdue University Press.

Garrison, J. (2010). *Dewey and Eros: Wisdom and desire in the art of teaching*: IAP.

Garrison, J., Neubert, S., & Reich, K. (2015). *Democracy and education reconsidered: Dewey after one hundred years*: Routledge.

Gay, W. C. (2018). Dewey's Political Ethics as Applied Philosophy that Advances International Peace *Nonviolence: Critiquing Assumptions, Examining Frameworks* (pp. 159-170): Brill Rodopi.

Gibbons, R. E., Villafañe, S. M., Stains, M., Murphy, K. L., & Raker, J. R. (2018). Beliefs about learning and enacted instructional practices: An investigation in postsecondary chemistry education. *Journal of Research in Science Teaching, 55*(8), 1111-1133.

Gilmanshina, S. I., Gilmanshin, I. R., Sagitova, R. N., & Galeeva, A. I. (2016). The Feature of Scientific Explanation in the Teaching of Chemistry in the Environment of New Information of School Students' Developmental Education. *International Journal of Environmental and Science Education, 11*(4), 349-358.

Goes, L. F., Fernandez, C., & Eilks, I. (2020). The Development of Pedagogical Content Knowledge about Teaching Redox Reactions in German Chemistry Teacher Education. *Education Sciences, 10*(7), 170.

Gonon, P. (2009). *The quest for modern vocational education: Georg Kerschensteiner between Dewey, Weber, and Simmel* (Vol. 9): Peter Lang.

Gordon, M. (2016). Why should scholars keep coming back to John Dewey? *Educational Philosophy and Theory, 48*(10), 1077-1091.

Gordon, M., & English, A. R. (2016). John Dewey's democracy and education in an era of globalization: Taylor & Francis.

Grammes, T. (2020). Democracy and Education (John Dewey 1916). *JSSE-Journal of Social Science Education, 19*(1).

Granger, D. (2016). *John Dewey, Robert Pirsig, and the art of living: Revisioning aesthetic education*: Springer.

Hachem, A. H. (2019). John Dewey and the "Problem" of the Mundane: Implications for Philosophy of Educational Administration *The Handbook of Dewey's Educational Theory and Practice* (pp. 345-365): Brill Sense.

Hansen, D. T. (2006). Dewey's book of the moral self. *John Dewey and our educational prospect: A critical engagement with Dewey's Democracy and Education*, 165-187.

Hansen, D. T. (2012). *John Dewey and our educational prospect: A critical engagement with Dewey's democracy and education*: SUNY Press.

Hansen, D. T. (2019). *Ethical visions of education: Philosophies in practice*: Teachers College Press.

Hayes, W. (2006). *The Progressive Education Movement: Is it Still a Factor in Today's Schools?* : ERIC.

Heilbronn, R., Doddington, C., & Higham, R. (2018). *Dewey and Education in the 21st Century: Fighting Back*: Emerald Group Publishing.

Hendley, B. (1989). Hirsch and Dewey on democracy and education. *Interchange, 20*(1), 53-60.

Hickman, L. A. (2017). Dewey, Pragmatism, Technology *The Oxford Handbook of Dewey*.

Hildebrand, D. (2018). John Dewey.

Hugerat, M. (2020). Incorporating Sustainability into Chemistry Education by Teaching through Project-Based Learning *Chemistry Education for a Sustainable Society Volume 1: High School, Outreach, & Global Perspectives* (pp. 79-96): ACS Publications.

Johnston, J. S. (2006). *Inquiry and education: John Dewey and the quest for democracy*: SUNY Press.

Keenan, B. (2020). *The Dewey experiment in China: Educational reform and political power in the early Republic*: Brill.

Kinnunen, P., Lampiselkä, J., Meisalo, V., & Malmi, L. (2016). Research on teaching and learning in Physics and Chemistry in NorDiNa Papers. *NorDina: Nordisk tidsskrift i naturfagdidaktikk*.

Koeper, I., Shapter, J., North, V., & Houston, D. (2020). Turning chemistry education on its head: Design, experience, and evaluation of a learning-centered 'Modern Chemistry'subject. *Journal of University Teaching & Learning Practice, 17*(3), 13.

Kousa, P., Kavonius, R., & Aksela, M. (2018). Low-achieving students' attitudes towards learning chemistry and chemistry teaching methods. *Chemistry Education Research and Practice, 19*(2), 431-441.

Kumar, S., Kumari, M., & Alam, S. (2018). Ground realities and inhibitions in the execution of MGNREGA in Jharkhand, India. *Asian Journal of Research in Social Sciences and Humanities, 8*(1), 74-93.

Kumari, M., & Alam, S. (2017). झारखण्ड के कंवर आदिवासियों में स्वास्थ्य संबंधी अवधारणाएं एवं मानवजाति चिकित्सकीय प्रथाएं (Perceptions Related to Ailments and Ethno-Medicinal Practices Among the Kawar Tribals of Jharkhand, India). *Research Reinforcement, 5*, 118-126.

Lagemann, E. C. (1996). Experimenting with education: John Dewey and Ella Flagg Young at the University of Chicago. *American Journal of Education, 104*(3), 171-185.

Lawrie, G. A., & Southam, D. C. (2018). Australian Chemistry Education Research and Practice: A Dynamic and Colourful Landscape of Learning and Teaching *International Perspectives on Chemistry Education Research and Practice* (pp. 175-191): ACS Publications.

LEE, T. T., SHARIF, A. M., & RAHIM, N. A. (2018). Designing E-content for teaching basic chemistry concepts in higher education: A needs analysis. *Journal of Turkish Science Education, 15*(4), 65-78.

LIU, Y.-h., JIANG, Y.-x., & LIN, H. (2017). Research on Promoting the Teaching of Chemistry Terms Based on the Law of Teenagers' Psychological Development. *Journal of Heilongjiang College of Education*(8), 26.

Liying, W. (2018). Chemistry Teaching Strategy Based on the Cultivation of Chemistry Core Literacy. *Shandong Chemical Industry*(9), 62.

Mack, M. R., & Towns, M. H. (2016). Faculty beliefs about the purposes of teaching undergraduate physical chemistry courses. *Chemistry Education Research and Practice, 17*(1), 80-99.

Mahaffy, P. G., Krief, A., Hopf, H., Mehta, G., & Matlin, S. A. (2018). Reorienting chemistry education through systems thinking. *Nature Reviews Chemistry, 2*(4), 1-3.

Malbrecht, B. J., Campbell, M. G., Chen, Y.-S., & Zheng, S.-L. (2016). Teaching outside the classroom: field trips in crystallography education for chemistry students. *Journal of Chemical Education, 93*(9), 1671-1675.

Markic, S., & Childs, P. E. (2016). Language and the teaching and learning of chemistry. *Chemistry Education Research and Practice, 17*(3), 434-438.

Martin, J. (2003). *The education of John Dewey: A biography*: Columbia University Press.

Newman, M. (2016). Philosophy of chemistry: unkempt jungle and fertile ground: Eric Scerri and Lee McIntyre: Philosophy of chemistry: Growth of a new discipline. Dordrecht: Springer, 2015. xii+ 233pp, $99 HB.

Novak, J. (1994). *Democratic teacher education: Programs, processes, problems, and prospects*: SUNY Press.

Orgill, M., York, S., & MacKellar, J. (2019). Introduction to systems thinking for the chemistry education community. *Journal of Chemical Education, 96*(12), 2720-2729.

Overton, T. (2019). Learning and teaching in chemistry *A Handbook for Teaching and Learning in Higher Education* (pp. 192-205): Routledge.

Pagliaro, M. (2019). Chemistry education fostering creativity in the digital era. *Israel Journal of Chemistry, 59*(6-7), 565-571.

Palmer, J., Bresler, L., & Cooper, D. (2001). *Fifty major thinkers on education: From Confucius to Dewey*: Psychology Press.

Pavlis, D., & Gkiosos, J. (2017). John Dewey, from the philosophy of pragmatism to progressive education. *Journal of Arts and Humanities*, *6*(9), 23-30.

Peters, M. (2017). Ecopolitical philosophy, education, and grassroots democracy: the "return" of Murray Bookchin (and John Dewey?). *Geopolitics, History, and International Relations, 9*(2), 7-14.

Peters, R. S. (2010). *John Dewey reconsidered (International Library of the Philosophy of Education Volume 19)*: Routledge.

Popkewitz, T. S. (2005). Inventing the modern self and John Dewey: Modernities and the traveling of pragmatism in education—An introduction *Inventing the modern self and John Dewey* (pp. 3-36): Springer.

Pring, R. (2017). Educational Philosophy of John Dewey and its relevance to current dilemmas in Education. *Education in the North, 24*(1), 3-15.

Prins, G. T., Bulte, A. M., & Pilot, A. (2018). Designing context-based teaching materials by transforming authentic scientific modeling practices in chemistry. *International Journal of Science Education, 40*(10), 1108-1135.

Priyambodo, E., & Wulaningrum, S. (2017). Using Chemistry Teaching Aids Based Local Wisdom as an Alternative Media for Chemistry Teaching and Learning. *International Journal of Evaluation and Research in Education, 6*(4), 295-298.

Quay, J., & Seaman, J. (2013). *John Dewey and education outdoors: Making sense of the 'educational situation through more than a century of progressive reforms*: Springer Science & Business Media.

Rautiainen, J. (2016). Problem-based chemistry teaching. *LUMAT-B: International Journal on Math, Science and Technology Education, 1*(3).

Reich, K. (2008). Democracy and Education after Dewey—Pragmatist Implications for Constructivist Pedagogy. *Reconstructing Democracy, Recontextualizing Dewey: Pragmatism and Interactive Constructivism in the Twenty-First Century. New York: Suny*, 55-88.

Rigney, J. (2017). A Primer for Philosophy and Education. Samuel Rocha. Eugene, OR: Cascade Books, 2014 Living as Learning: John Dewey in the 21st Century. Jim Garrison, Larry Hickman, and Daisaku Ikeda. Cambridge, MA: Dialogue Path Press, 2014: Taylor & Francis.

Saito, N. (2005). *The gleam of light: Moral perfectionism and education in Dewey and Emerson*: Fordham Univ Press.

Saltmarsh, J. (2008). Why Dewey matters. *The Good Society, 17*(2), 63-68.

Schubert, W. H. (2010). *Love, justice, and education: John Dewey and the Utopians*: IAP.

Seigfried, C. H. (2010). *Feminist Interpretations of John Dewey*: Penn State Press.

Semetsky, I. (2006). *Deleuze, education, and becoming*: Brill Sense.

Shekhovtsova, T. (2018). The current state of analytical chemistry teaching in Russian universities. *Analytical and Bioanalytical Chemistry, 410*(17), 3917-3924.

Shook, J. (2017). The nature philosophy of John Dewey. *Dewey Studies, 1*(1), 13-43.

Sikandar, A. (2016). John Dewey and his philosophy of education. *Journal of Education and Educational Development, 2*(2), 191-201.

Silalahi, A. (2016). PHILOSOPHICAL PERSPECTIVES THAT DESCRIBE HOW THE WORK IN CHEMISTRY EDUCATION.

Stojanovska, M., Mijic, I., & Petrusevski, V. M. (2020). Challenges and recommendations for improving chemistry education and teaching in the Republic of North Macedonia. *CEPS Journal, 10*(1), 145-166.

Taber, K. S. (2016). Learning generic skills through chemistry education. *Chemistry Education Research and Practice, 17*(2), 225-228.

Taysum, A. (2019). A Dewey Framework for Moral Training for Democracy in Education *The Handbook of Dewey's Educational Theory and Practice* (pp. 137-153): Brill Sense.

Walker-Coté, H. (2019). Comparative Assessment in John Dewey, Confucius, and Global Philosophy. *Education and Culture, 35*(1), 105-108.

Wang, M.-Y., Li, X.-Y., & He, L.-N. (2018). Green chemistry education and activity in China. *Current Opinion in Green and Sustainable Chemistry, 13*, 123-129.

Wei, B., & Liu, H. (2018). An experienced chemistry teacher's practical knowledge of teaching with practical work: the PCK perspective. *Chemistry Education Research and Practice, 19*(2), 452-462.

Weiqing, Z. (2018). Analysis of Application of Thematic Teaching Method in Organic Chemistry Experiment Teaching. *Yunnan Chemical Technology*(6), 107.

Wheeler, L. B., Maeng, J. L., & Whitworth, B. A. (2017). Characterizing teaching assistants' knowledge and beliefs following professional development activities within an inquiry-based general chemistry context. *Journal of Chemical Education, 94*(1), 19-28.

Winston, J. (2019). Teaching Chemistry as a Story: Using Narrative Structure as a Framework for Science Education. *Electronic Journal of Science Education, 23*(3), 59-72.

WU, S., & LOU, Z.-w. (2017). *A study on the Feasibility of Senior High School Chemistry Stratify Teaching Strategy.* Paper presented at the Education Teaching Forum.

XIE, D., & LI, J. (2017). Research on the Teaching Reform of Analytical Chemistry Experiment in Applied Undergraduate Colleges. *Journal of Huaibei Normal University (Natural Science Edition)*(1), 18.

Zembal-Saul, C., & Vaishampayan, A. (2019). Research and practice on science teachers' continuous professional development in argumentation *Argumentation in Chemistry Education* (pp. 142-172).

ZHANG, J., ZHAO, Y., & ZHANG, D.-H. (2016). Problems and Solutions of PBL Teaching Method in Organic Chemistry Teaching. *Chinese Journal of Chemical Education*(18), 6.

ZHAO, S.-J., LI, M.-t., HONG, B., & ZHU, H. (2017). *Study on Organic Chemistry Teaching Based on Students' Self Regulated Learning.* Paper presented at the Education Teaching Forum.

ZHU, L., FENG, X., CHEN, L., & TIAN, Y. (2018). The Extensions on the Classroom Teaching for Basic Physical Chemistry Experiments. *Experiment Science and Technology*, 06.

Zotos, E. K., Moon, A. C., & Shultz, G. V. (2020). Investigation of chemistry graduate teaching assistants' teacher knowledge and teacher identity. *Journal of Research in Science Teaching*.