

## **Nature of Problem-Solving Skills for 21st Century STEM Learners: What Teachers Need to Know**

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### **ABSTRACT**

Since the emergence of the fourth industrial revolution which calls for a new model of learning for the twenty-first century learners, it has been argued that the nature of problems that learners must solve in science, technology, engineering and mathematics (STEM) must also be transformed to enable new forms of learning skills that are needed to tackle complex global challenges. However, the question of how best to teach these skills purposefully and explicitly is largely overlooked. STEM education reformers recognize that the lecture method or traditional method of teaching is highly ineffective for teaching twenty-first century competencies and skills that learners need to develop, yet widespread use of this approach continues. In today's world, we need STEM graduates who are more sophisticated in understanding the uncertainty of knowledge through quasi-reflective thinking when there is uncertainty about a solution to a problem. For this to happen, STEM learners need skills such as critical thinking, decision-making, innovation, the ability to communicate new knowledge effectively, and the ability to solve various kinds of problems through negotiation and collaboration, all of which present a corpus of knowledge to be constructed and mastered in a learner-driven pedagogy. Therefore, rethinking the kind of problem-solving skills we teach twenty-first century learners is as crucial as identifying a suitable instructional model. This paper demonstrates how the domain of ill-structured problems-based learning may contribute to the development and mastery of twenty-first century competencies and skills and advance the quality of learning through the argumentation model.

*Keywords:* Cognition; arguments; STEM; teachers; twenty-first century learners; ill-structured problem solving; skills

The world of science, technology, engineering and mathematics (STEM) education is in a state of flux. New types of jobs, knowledge, and skills are emerging, requiring future STEM graduates to be well equipped to meet the need of the expansion requirements of today's workforce. STEM teacher education must keep abreast of the macro and dynamic changes in the type of knowledge and skills required of STEM graduates. However, a STEM workforce is needed to solve many of the world's social, economic, and environmental problems (National Research Council, [NRC], 2011; UNESCO, 2012). From a teaching perspective, the focus on the skills required for a knowledge-based society (often referred to as twenty-first century skills) raises questions about

the nature of problem-solving skills we teach in STEM fields. What alternatives are there for developing twenty-first century STEM learners with the knowledge and skills needed to confront ever-expanding global challenges? Thus, STEM teacher education is faced with a massive challenge of what needs to change. This paper provides insights and suggestions of the kind of problem-based learning and projects STEM teachers need to know that may offer opportunities for their learners to practice and apply knowledge resources in a variety of contexts. This includes relevant examples of real-life problems (see ISP#1 and Figure 2) that can help learners to engage in epistemic cognition, examine multiple solutions, make and defend judgments, and communicate new knowledge. Prior research suggests that some forms of pedagogy are consistently more successful than others in helping learners acquire a deeper understanding of twenty-first century skills (Netwong, 2018; NRC, 2011; Slough & Chamblee, 2017). On this point, this paper also shows how the argumentation model can be used to provide learning situations that encourage critical thinking and problem-solving skills.

One important aspect of STEM teacher education is to equip learners to become competent problem solvers because of the dynamics of the job environments in which they will find themselves in the future. Literature on this topic offers compelling arguments for transforming the nature of problems that learners solve in STEM fields to better support the acquisition of twenty-first century skills (Jamaludin & Hung, 2017; Netwong, 2018; NRC, 2012). Despite this, little emphasis is laid on teaching the skills and understanding involved in achieving these objectives. In many countries, STEM teaching has been mainly driven by tradition-led teaching approaches where textbooks are sometimes the go-between the teacher and the learners (NRC, 2011; UNESCO & UNICEF, 2013a). However, textbook problems are well structured – even those that invoke a supposed real-world context are not as messy as a learner’s real life often is. Textbook problems are limited in their ability to provide opportunities to practise important aspects of the twenty-first century competencies and skills desperately needed to confront persistent global challenges (King & Kitchener, 2004). Besides, many problems confronting us in this twenty-first century are not well structured; most have no clear answers or solutions.

Spector and Park (2012) have listed some interesting examples of ISPs that can be found in nearly every aspect of life as well as in STEM subject domain, they include: (i) the design of a bridge to span a particular body of water, (ii) determining how best to treat a patient suffering from multiple chronic illnesses, (iii) finding the fault or faults in an electronic circuit that fails intermittently, (iv) the development of an economic policy to resolve a persistent budget deficit, and (v) planning a large social event. Certainly, ill-structured problem (ISP) solving is a prominent example of a twenty-first century skill, because the current and future global problems, as well as problems in our daily lives, are typically ill-structured. Therefore, the inclusion of essential twenty-first century skills, such as learning how to solve difficult ill-structured problems and learning how to collaborate, can help STEM learners to address enduring or emerging issues confronting them (Facer, 2012; Jamaludin & Hung, 2017). If the twenty-first century learners’ competencies and skills are to be properly instilled, we must clearly answer questions about the amount, appropriateness, and relevance of the nature of the problems to which we expose them. More will be said about this in the succeeding sections.

## **Why Should We Engage the 21<sup>st</sup> Century Learners to Ill-structured Problem-based Learning?**

Real-world experience shows that many problems that learners encounter in their everyday life are ill-structured. Many teachers probably have seen their learners wrestling with issues of finding methods for resolving perplexity where they must make and defend judgements between evidence and a point of view, and how to evaluate such evidence on different sides of issues. As it is in real life, ISPs often possess either multiple or no clear solutions, and because of this, we say they are ill-structured (King & Kitchener, 2004). According to Jonassen and Hung (2008), the complexity of an ISP can be determined by four aspects: (i) the breadth of knowledge required to resolve it, (ii) the difficulty level of the major concepts in the problem, (iii) the intricacy of problem-solution procedures, and (iv) the relational complexity among major concepts in the problem. A problem whose structure accompanies all these kinds of descriptions is characterized as an ill-structured problem (ISP). Normatively, ISPs present a degree of uncertainty about concepts, rules and principles that might be necessary for proposing solutions (Jonassen, 2011a; Shekoyan & Etkina, 2007; Voss, 2006). It surely must follow that engaging STEM learners in ISP solving is important because we all need ill-structured problem-solving skills in order to cope with everyday life. Many researchers view ISP solving as a lifelong learning skill that we need to teach the twenty-first century learners (Facer, 2012; Jamaludin & Hung, 2017; King & Kitchener, 2004; NRC, 2012). To achieve this goal, STEM teachers need to ensure that ill-structured problem-based learning is meaningful, worthwhile and feasible, because a lack of relevance leads to a lack of motivation, which ultimately results in decreased levels of learning (Saavedra & Opfer, 2012).

### **Ill-structured Problem-based Learning and Project: Teacher's Role**

What ultimately makes ISP-based learning and projects meaningful? With ISP-based learning and projects, learners learn by designing and constructing actual solutions to real-life problems (Trilling & Fadel, 2009), carry out detailed research projects, solve various kinds of problems as they arise, make and defend judgements in the face of complexity and uncertainty (King & Kitchener, 2004), and communicate new knowledge that has genuine value for them personally and their communities (Barron & Darling-Hammond, 2008). For this to work well, teachers must design curricula activities that match the interests and the needs of their learners (Barkley et al., 2014). Research by Barron and Darling-Hammond (2008) shows that deeper learning takes place when learners can apply classroom-gathered knowledge to real-world problems and take part in projects that require sustained engagement and collaboration (see Figure 2 and ISP#1). By virtue of their nature, addressing ISP-based learning and projects require judgements, planning, and the use of strategies and the implementation of previously learned skill repertoires (King & Kitchener, 2004). Therefore, it should be noted that completing such activities may not easily fit into the standard '50-minute classroom period', so alternative scheduling should be considered (Trilling & Fadel, 2009, p. 114-115). Further to this, addressing ISP helps develop inquiry skills among learners as they become researchers, seeking out and evaluating new information, collaborating with their peers to tackle problems, and revising existing knowledge (Facer, 2012). ISP-based learning can also help to enhance learners' interest in learning, develop in them a strong knowledge base in the relevant disciplines, and strengthen their integrative learning and application of the essential skills and qualities required in the twenty-first century.

Given the importance of fostering twenty-first century competencies and skills through ISP-based learning and projects, it may not be important to continue teaching only well-structured problems (WSPs) to learners in STEM fields, especially at high school, college and university levels. The point is that the condition of a WSP is invariably satisfied by a given solution, which leaves no room for alternatives. Very often a solution obtained from solving a WSP is considered in isolation from the others as it serves an end to its confined computation. This does not imply that all WSPs within the defined domain can be solved with only reasonable amounts of computation. Some are solvable in principle; many may require immense numbers of applications of operators and tests for their solution, so that the total amount of computation required may be impractical (Jonassen & Hung, 2008; Simon, 1973). By contrast, ISPs are characterized indifferently when solving them. In most cases, the goal is vaguely stated, and requires analysis and refinement in order to make the particular issue tractable (Voss, 2006). In this connection, teachers should choose ISPs most suited to the needs and interests of learners to help them to develop and apply generic skills (e.g. critical thinking and collaboration skills, creativity, originality, strategizing, communication), and subject-specific skills. The ability to develop these skills for use in solving ISPs is something that some learners may find easy to develop, while others may not. Likewise, because of personal difference, a concept explained in one way may be grasped by some learners while it may puzzle others.

Teachers who are concerned about the ISP solving ability of their learners should realize that they can make a difference. For the ultimate benefits of learners, it is good to establish very simple steps on how to solve ISPs. The learners' curiosity is at first qualitative; let that be whetted first, and then turned into a quantitative direction gradually. Depending on the age group of learners, the traditional role of the teacher as dispenser of facts and as the source of knowledge is only a small part of the pattern. The teacher is given a more important function to ask questions that provide learners the freedom to resolve the problem as they see fit. Encourage the learners to find out things for themselves, and do not tell them more than is really necessary. Let them ask questions about the problem, but as often as possible answer the questions by asking other questions which will put them on a new line of meaningful inquiry. To further encourage learning, the teacher may ask learners to design or construct their own ISPs that have genuine value for them. This can be a daunting task for both teachers and learners as it might not be easy to pay attention to details regarding each learner's conception of an ISP. Nevertheless, achieving this in STEM classroom has to be done in a way that is manageable, and in most cases, has to take place in small-group rather than in large-group situations.

In today's world, we need STEM graduates who are more sophisticated in understanding the uncertainty of knowledge through quasi-reflective thinking when there is uncertainty about a solution to a problem. Therefore, an appropriate educational goal for STEM learners when they address ISPs is to learn to construct and defend the reasonable solutions they propose. An important key to success in teaching ISP solving in STEM fields will be an appropriate choice of problems to solve, and instructional approaches and expectations, so that they match the learners' interests and abilities. As an example, the following task (ISP#1) represents a variety of major disciplines (e.g. physics, mathematics, geography, life science, etc.). The task could be regarded as an immediate class task where learners are invited to address the problem, or it can be assigned to learners as a research project. Whichever we see necessary, sufficient time must be given to learners to address the problem.

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ISP#1: Concept of vectors-featuring life in the Sahara Desert

*Every day we hear stories of people being stranded in the Sahara Desert. Many survivors have shared their stories of how helpless they felt to find a way as there are often no landmarks or clues to guide them. However, the Sahara Desert is a home to many ants, such as *Cataglyphis forties*. When one of the ants forages for food, it travels from its home nest along a haphazard search path searching for food. The ant may travel more than 500m along such a complicated path over flat, featureless sand that contains no landmarks. Yet, when the ant decides to return home, it turns and then runs directly home.*

How does the ant know the way home with no guiding clues on the desert plain?

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Learners are invited to use their integrated knowledge resources of various subjects to address the problem. Physics learners might approach the problem using a variety of vector concepts and analytical tools of epistemological framing, as well as blending ancillary information with the use of math-in-physics. Mathematics learners may use their knowledge of bearings to develop and defend mathematical arguments. Life science learners may use their knowledge of bifurcation and topological change in relation to the behavior of the ant to develop and defend arguments. Geography learners may approach the problem using their knowledge of geomorphology, by tapping into plane Euclidean geometry, spherical geometry, trigonometry, and so on. In all cases, learners must draw upon relevant knowledge, present a reasonable solution, and support it with sound arguments as well as producing grounds to refute an anticipated opposing position.

### **Teaching 21st Century Competencies and Skills through Argumentation**

The twenty-first century learners need an instructional approach that offers learning opportunities through authentic real-world contexts. A growing body of research shows that collaborative learning is a twenty-first century trend that shifts learning from teacher or lecture-centered settings to learner-driven settings. In the latter setting, teachers must ascertain what knowledge resources individual learners have acquired or still need to acquire, so that they can decide whether to move forward with covering the curriculum or reviewing existing ways of knowing in greater depth (Barkley et al., 2014; Facer, 2012). In the manner now being indicated, learner-centered teaching merged with argumentation can offer great opportunities to prepare the twenty-first century learners for life beyond graduation. Kuhn (2010) and others (Belland, Glazewski, & Richardson, 2011; Evagorou & Osborne, 2013; Ogunniyi, 2007a) state that an argument is a form of discourse that needs to be appropriated by learners and explicitly taught through suitable instruction, task structuring and modelling (Simon et al., 2006). Thus, argument refers to the substance of claims, data, warrant, and backing that contributes to the content of the argument, whereas argumentation refers to the process of assembling these components, as espoused by Toulmin (2003). From this perspective, argumentation is the process of making a claim and providing justifications for the claim using evidence (Kuhn & Udell, 2007).

Therefore, situating argumentation as a central element in the design of ISP-based learning and projects has two functions: (1) how arguments are used by learners in STEM fields for the construction of projects or ISPs solution pathway; and (2) the development of criteria used by learners in STEM to evaluate the selection of evidence and the construction of explanations to refute an anticipated opposing position when it arises. What this then means is that STEM should not only involve transmitting a set of known facts to learners, but should also focus on encouraging

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learners to engage in critical and inventive thinking about STEM concepts, to support their claims using evidence, and to justify their ideas with practicable explanations (Kuhn, 2010; Voss, 2006). This should be seen in relation to providing learners with an ISP-based learning activity which supports equitable opportunities for collaboration, discussion and debate and teacher-learner active engagement in constructing arguments through the process of argumentation (Belland et al., 2011; Simon et al., 2006).

In order for each learner to be able to pursue his or her own course of action during ISP solving, the teacher should see to it that the conduct and organization of the class should at least support three practical forms of argumentation: *analytical*, which is grounded in the theory of logic and proceeds inductively or deductively from a set of premises to a conclusion; *dialectical*, which occurs during discussion or debate; and *rhetorical*, which is employed to persuade an audience (Toulmin, 2003). The teacher should realize that, to conduct argumentation instruction well, proper preparation is essential. The unprepared teacher will not be in a position to ask questions or make comments that will help to bring his/her learners to the point where they will be able to reach reasonable conclusions for themselves. Also, the teacher should have such a good grounding in the subject that he/she can visualize what the course and outcome of the argument is likely to be, even if the discussion takes an unexpected turn, his/her background in the subject would then help to deal with the situation.

Furthermore, some teachers tend to monopolize the discussion, intervene too soon on behalf of a speaker, and supply additional information themselves. It is important that the learner should, in his/her struggle to express himself or herself clearly, be given the opportunity to arrange his/her thoughts and improve his/her powers of expression. What the learner needs at this stage is the encouragement given by the teacher in order to advance to a higher level of thought. They should have the chance to reason, think, argue, critique the problem and the propose solution(s) as they see fit, make and defend their judgements and communicate the outcome in their own words. The teacher should not take over this burden from the learners. Learners going out of their way to talk over their peers, or to prove how clever they are, can spoil the purpose of teaching and learning ISP solving through argumentation. It is important that learners should be willing to listen and to take one another seriously. The example of the teacher is extremely important in this respect. Therefore, the creation of a respectful atmosphere in which learners can enter into a dialogue or conversation about a given problem is essential. The teacher should be friendly and natural at all times, but business-like rather than an authoritarian or a slack. Without these basic requirements, teaching ill-structured problem solving through argumentation instruction can become little more than time-wasting chatter or a nightmare to learners.

An important insight that has developed from the researcher's prior work shows that it is important not only for learners to be able to make sense of data to construct claims, but also to be able to consider alternative claims and to critique the claims and justifications provided by their fellow learners in the context of dialogic interactions (Iwuanyanwu, 2019). As an example, a learner is assigned to solve the ISP#1, titled "concept of vectors-featuring life in the Sahara Desert". The question reads, '*how does the ant know the way home with no guiding clues on the desert plain?*' First, the learner will need some form of model that supports the construction of a problem representation phase. The model may consist of a Claim, which is the basic argument, the Grounds (or Warrant, which relates to the Data and Claim), and the possible Backing for the Claim. For example, the learner makes a Claim that "*the desert ant keeps track of its movements along a*

*mental coordinate system*”. This Claim can then be challenged by his or her peers who might ask ‘what reasons have you got to go on?’ The learner can then appeal to the relevant knowledge resources at his or her disposal, known as Data. In addition, the learner can support his or her line of reasoning using a problem representation phase (vector diagram), which presumably points to the locus of the ant’s home nest (Figure 1). At this point, whether the facts provided by the learner (solver) are accepted by the challenger or not, do not necessarily end the argument. This allows the claim of one argument to serve as the data of a second argument, thus permitting argument continuity. Following this, the challenger may ask the learner (solver) about the bearing of data on the claim that he or she has made. For example, by asking the question, ‘how do you get there?’ This question engenders the construction of a proposition known as the Warrant. By this, the learner (solver) must have recourse to use data to make a conclusion or claim. The learner goes on to say that “*when the desert ant wants to return to its home nest, it effectively sums its displacement along the axes of the mental coordinate system to calculate a vector that points directly home*”.

Again, different degrees of force on the conclusions may be raised by the challenger, *indicating circumstances in which the authority of the warrant is set aside*. The challenger may ask ‘Why do you think that?’ Thus, the learner (solver) will have to provide an answer that corroborates his or her thought. As backing, the learner (solver) may point out that the proposed mental coordinate system of the ant would permit some form of calculations, by taking variables and instances (shown in Figure 1 below) as constrain conditions to be examined on their own merit. As an example of such calculation, let us consider the ant making five runs of 6cm each on an  $(x; y)$  coordinate system, in the direction shown in Figure 1, starting from home.

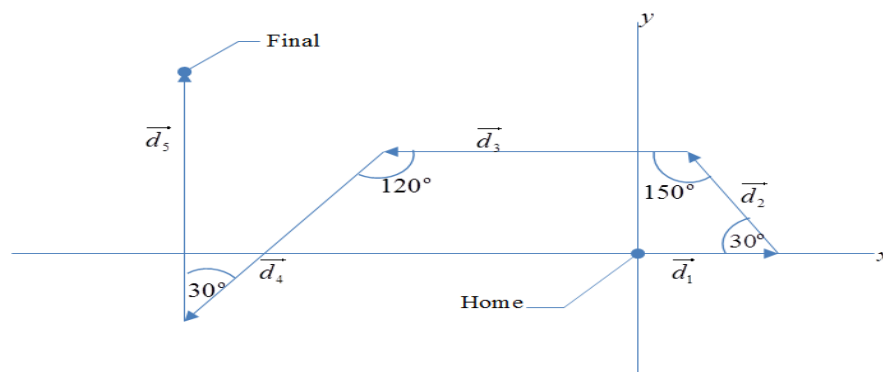


Figure 1. Representation of mental coordinate system of the ant’s movement.

The learner (solver) can propose solutions for what he or she thinks the magnitude and angle of the ant’s net displacement vector presumably are, and what those are of the homeward vector that extends from the ant’s final position back home. Having made this point, the learner acknowledges that different solutions are possible. We consider those that we think are worthy of consideration, rule out some and leave them undetermined until more convincing evidence emerges.

In another related case, a teacher may, for example, design an activity that shows the need for aid relief supplies to be transported to an area where the road leading to the aid recipients is blocked (Figure 2). Some explanation may be helpful for understanding how the task can be approached. The teacher may ask learners to design a simulation vehicle, which is capable of transporting goods, able to navigate down slopes, and, if obstacles are encountered, should be able to launch

its cargo successfully to the desired target (Yu et al., 2015). The composition of the task requires various STEM sources such as knowledge of classification, terminology, principles, theories, models, structures, algorithms, and strategies needed to execute the task. Since the nature of the task depicts a teaching and learning approach in which science, technology, engineering, and mathematics (STEM) are purposely integrated, learners will need to develop a utility blending of auxiliary information for STEM problem organization and solution. This may lead to a higher form of awareness, and consequently, to a deeper level of understanding from which ideas may move within a learner's mind when discussing the nature of the task with his or her peers.

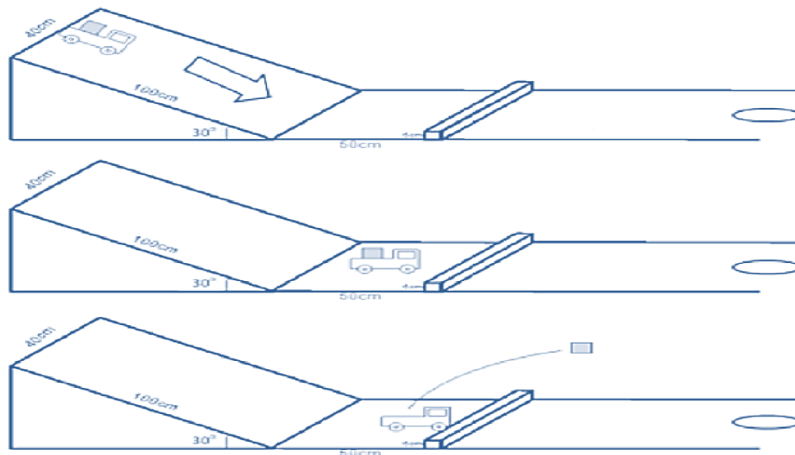


Figure 2. ISP-based learning activity adapted and modified after Yu et al. (2015)

Furthermore, the nature of the task offers opportunities for learners to imagine the problem context and what the key features of the simulation vehicle are, including both visible and invisible features. This involves negotiating both logical and non-logical ideas among learners from a variety of STEM sources. Thus, the utilization of argumentative elements (e.g., claim, evidence, warrant, counterclaim, and rebuttal) and their application within the scope of the problem are essential in fostering reasoning skills among learners to judge the adequacy of the problem solution. Depending on the nature of the arousal context, or the claims to be defended or refuted in the strife to attain a sort of cognitive allostasis, learners with divergent opinions about the task will seek to justify their stances against those of real opponents (Ogunniyi, 2007a). As such, their thinking is directed to analyze and define the problem in a systematic and alternative way, yet leaving a tolerance for ambiguity. This then requires learners to postpone judgment in the evaluation of various options, keep an open mind for alternative solutions, and curiously but skeptically look for other solutions even when one is at hand. It also requires them to carefully analyze STEM resources to help them identify salient features of the problem. In doing so, they make claims and defend their claims or counterclaims with reasonable arguments. At any rate, they make decisions and adopt a plan for solving the problem. The plan to be implemented must be attentive to details. At the beginning of implementation, the learners apply whatever level of understanding they have in STEM domains, and see if they can reach a satisfactory solution. In the event of not being satisfied, the learners are then encouraged to stretch towards a more satisfactory solution by working further in some newish areas (other domains) until they obtain more satisfaction.



To integrate the foregoing into a sensible mental framework, STEM teachers may want to assess the dynamic cognitive states that each learner or group of learners adopt while trying to solve the problem. The key issue that has to be considered is that learners will differ according to the STEM sources from which they cultivate their argument and in the levels to which they develop it. Therefore, to create the needed intellectual space for appraising the interface of STEM ideas as they unfold while the task is being executed, Ogunniyi's (2007a) Contiguity Argumentation Theory (CAT) provides valuable theoretical and analytical support for evaluating what counts as feasible solutions to the task in terms of the logical and non-logical arguments that learners will generate. Essentially, CAT consists of five dynamic cognitive stages (i.e. dominant, suppressed, assimilated, emergent and equipollent) that teachers can use to evaluate learners' ideas while executing intricate tasks. During each of these stages, there is a unique level of analysis, an internal organization and understanding of the cognitive shift that happens in the mind of the learner. Dominant refers to a learner's most prevalent worldview or ideas being mobilized within (or across) STEM fields to solve a problem. Suppressed refers to a learner's thought system in which a unit of STEM ideas is subdued by the more dominant one. Assimilated refers to a unit of STEM ideas that is subsumed by the more dominant one. Emergent refers to the STEM ideas that evolve from a new experience, e.g. the acquisition of a new concept in STEM fields. Equipollent refers to two or more STEM ideas exerting equal cognitive force on a problem solver's solution pathway. This again requires STEM teachers to make the ways in which learners' ideas unfold explicit to learners. In a way that is appropriate to the particular circumstances, learners learn not only what counts as justifiable solutions, but how the execution of the problems, such as those depicted in Figure 2 and ISP#1, fit into evidenced-based argumentation. The strength of such an approach is that learners can look back with objectivity over the entire process, and communicate their new knowledge to others, and additionally, show how the learned knowledge and skills can be applied to other contexts.

### **Constructing Solutions of Ill-structured Problems**

The arguments presented so far have shown that ISP-based learning can create new and unprecedented opportunities for learners to develop the essential skills needed to solve STEM problems that are ever-present in real life where WSP-based learning alone is insufficient. The highlights of Figure 2 and ISP#1 buttress this viewpoint. However, some evidence agrees that there are aspects of the teacher's own problem-solving behavior which they do not include in their teaching (Jonassen, 2011a; Shekoyan & Etkina, 2007; Yu et al., 2015). These include the careful reading and re-reading of the problem statement, its translation into sub-problems and required information, the choice of the strategy to be used, and the systematic checking of their implementation of each of its steps. Therefore, to translate these omissions into pedagogy for teaching ill-structured problems (ISPs), this paper suggests that teachers should:

- place an emphasis on the ways to read and translate the statement of ISP.
- engage learners in an active construction of various representation phases of ISPs.
- use explicit teaching strategies of ISPs to demonstrate how they themselves go about solving an ISP.
- recognize that different ISP solvers may vary considerably in the nature and contents based on their knowledge, beliefs, and attitudes.

- know that an ISP may have multiple solutions, and therefore should be judged in terms of some level of plausibility or acceptability.
- know that solutions learners propose to ISPs are justified by arguments that indicate why the solutions will work, as well as producing grounds to refute an anticipated opposing position.
- emphasize that the solutions of ISPs often are not final, in the sense that they need to be implemented (tested) and evaluated to see if it will really work (Voss, 2006).

As opposed to WSPs, the constraints of ISPs, such as found in everyday life or in many subject matter contexts, typically are not in the problem statement (Voss, 2006). The problem solver (learner) needs to retrieve and examine the constraints (as depicted in Figure 3), when appropriate, during the solving processes.

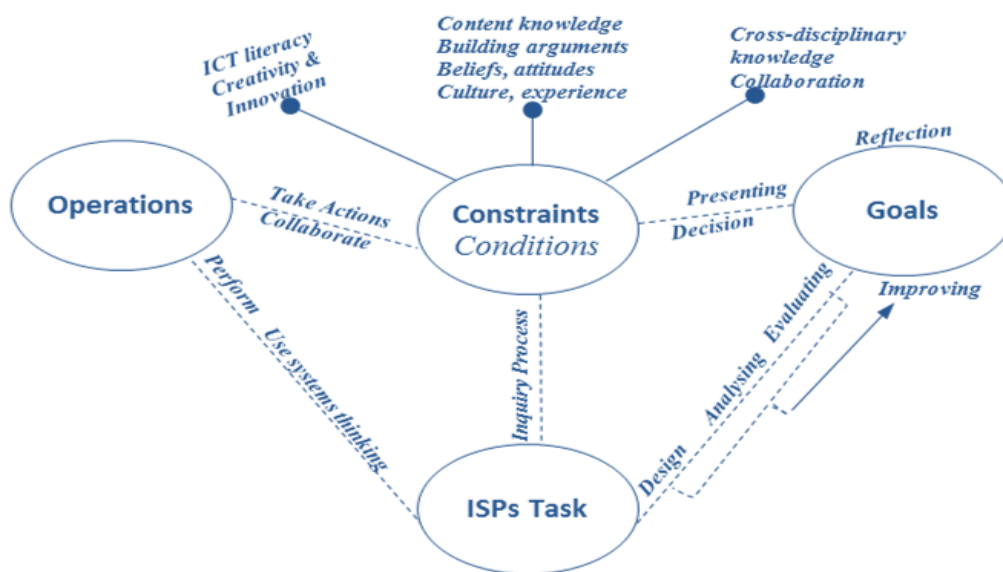


Figure 3. Integrated features of ISPs depicting utilization of many skills.

Figure 3 shows the perspective of an ISP task depicting the activity-processing features that can be advanced by a problem solver in relation to particular task goals. Taking appropriate action to solve an ill-structured problem is realized through operations directed by constraints or conditions which include learners' existing knowledge, experience, intellectual capacity, and the resources and tools available to achieve the desired goals. Available evidence suggests that the acting problem solver (learner) is motivated by unanticipated interruptions to the flow of the solution process. Evidence is shown in Tweney's (1981) study of Michael Faraday's notebooks during the course of Faraday's discovery of electromagnetic induction. The solution process quite substantially followed the course of solving ill-structured problems. On the basis of this assertion, investigating whether a student knows "p" will inevitably include watching him or her do something that closely resembles "p". If knowing and doing are so closely intertwined (Barron & Darling-Hammond, 2008), one should not ignore the real-world setting in which the learner does "p".

As an example, assume the problem is to find if a physics learner can demonstrate evidence that s/he can retrieve and examine the constraints embedded in the fourth equation of the Lorentz

transformation  $t' = \frac{t - \frac{v}{c^2}x}{\sqrt{1 - \frac{v^2}{c^2}}}$  as well as producing grounds to refute an anticipated opposing

position. The learner may begin by constructing the representation phase of the equation. However, doing so may not satisfy other indicators of understanding, such as recognizing the interplay between each symbol and any other with which it may appear. One move the learner is likely to make is to ascertain conditions to which each of the variables of the equation applies or does not apply. Essentially, the same tenet holds if the learner must resolve that time difference  $\Delta t'$  of the two events with respect to  $K'$  in general does not vanish, even when the time difference  $\Delta t$  of the same events with reference to  $K$  vanishes. In the main, the pure “space-distance” of the two events with respect to  $K$  results in “time-distance” of the same events with respect to  $K'$ . At this point, the teacher may need to ascertain whether the learner also recognized the most essential property of the equation as a three-dimensional (3D) continuum of Euclidean geometrical space. The difficulty in recognition affects other cognitive factors, such as the strategy a problem solver employs to create a solution as well as the host of arguments generated to support the solution (Belland et al., 2011).

To help learners in STEM fields acquire mastery in this area and become experts in producing knowledge rather than consuming it, we must capitalize on their interests by ensuring the ultimate goal of ill-structured problem-based learning and projects is to stimulate their capacities to create and generate ideas, concepts and knowledge (Jamaludin & Hung, 2017; Jonassen, 2011a). In the same vein, it is imperative to recognize when learners cannot immediately achieve those goals. STEM teachers should set intermediate targets for learners by breaking down learning into meaningful segments, so that interest is sustained (Netwong, 2018; NRC, 2012).

### **Implications for the 21st century STEM pedagogy**

What is next for equipping twenty-first century learners with the skills and competencies to function in the ever-expanding global digital world, known as the fourth industrial revolution? Most likely, pressures may vary from discipline to discipline, but the message is fundamentally the same for science, technology, engineering and mathematics (STEM). Re-skilling and updating competencies will enable learners of all ages to adapt to new STEM expectations in the twenty-first century workplace and life. Ultimately, assessment that focuses on a learner’s mastery of STEM’s core academic content and the development of deeper learning skills (i.e. critical thinking, problem solving, collaboration, communication and metacognition) should be a high priority (Gijisbers & Schoonhoven, 2012; Jamaludin & Hung, 2017; NRC, 2012; UNESCO & UNICEF, 2013a). To foster this commitment as the paradigm for the future is to expect that learning strategies and pedagogical approaches will undergo drastic changes and create new pathways for learners of all ages. Information and Communications Technology (ICT) should also be used to permeate learning activities and be integrated into learners’ real-world experience as a way to foster creativity and innovation. The proposal for using ISP-based learning and projects with linkage to argumentation instruction can be a way to equip learners to tackle twenty-first century challenges and pressures. However, a necessary collocation to this is that formative assessment must be appropriated as a practice to support learners. Thus, the attainment of this will equally

require teacher education programmes to shift their orientation to twenty-first century principles of teaching and learning.

### Closing Thoughts

As this paper has clearly demonstrated, one clear goal of ISP-based learning for STEM learners is that different individuals can have different but reasonable positions on the same issue. Fundamentally, therefore, whatever we teach them must be taught thoroughly so they can use it confidently and correctly in whatever decisions they later make, whether in their private lives, in societies or in their future professions. This also means that STEM teachers must ascertain the individual learners' process of adapting new knowledge for their own use and incorporating it into their existing knowledge and skills. This, in turn, nurtures critical thinking skills, creativity, originality, and establishes new cognitive habits (Lai, 2011). However, for transfer to occur, learners need to apply new learning and practice new skills in different situations and contexts.

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