Turkish Online Journal of Qualitative Inquiry (TOJQI)

Volume 14, Issue 1, January 2023: 12-23

Technology-Enhanced Inquiry Tool in Science Education: An Inclusive Pedagogical Framework for Classroom Teaching and Learning Practices

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Abstract

Technology is radically transforming teaching and learning, as inquiry-based digital information resources and creative tools are made available to learners, schools and educators. This study explores discusses a range of inquiry-based pedagogical approaches that teachers can utilize for effective teaching of science education. Technology skills are one set of 21st century skills that support effective teaching and learning. The idea of inquiry-based learning is to foster characteristics of good learners and encourage them in the educational process. These characteristics include confidence in the ability to learn, enjoying problem-solving, trusting one's own judgement, not fearing being wrong, a flexible point of view, and respect for facts. The Inquiry-based learning, teaching and learning contexts in science education classrooms practices were highlighted. Contextual teaching and learning strategies highlighted include inquiry learning, problem-based learning, cooperative learning, project-based learning, and authentic assessment. In order to use these contextual teaching and learning strategies to be used effectively, technology enhanced inquiry tool should be used for effective teaching and learning.

Keywords: Inquiry-Based Learning, Technology, Technology-Enhanced Inquiry, 21st Century Skills

1. Introduction

There has been a paradigm shift in education moving away from a traditional, passive, lecture-style teaching, towards active student-centered learning in which students self-regulate their learning. In science education, there are various types of active student-centered learning including: inquiry based learning, project-based learning, and discovery learning. As a result, the “new pedagogy” as described by **Fullan (2012)** emerged, shifting the fundamental role of teachers from instructors to learning partners. This new way of teaching and learning can be supported by the acceleration of technology (**Fullan, 2012**). Globally, we live in an advanced technological era, where student have increased digital skills, access to new technological tools and a plethora of resources on the web.

Technology must be used to expand students' knowledge base in a way that would be impossible without its use. Teachers no longer tasked themselves with teaching computer skills, but rather on how to prepare students to be 21st century learners and workers. Information, media and technology skills are one set of 21st century skills that support effective teaching and learning. The invention of technologies has helped students to collect information as well as to input and manipulate data immediately (**Norris & Soloway, 2003**). Furthermore, access to the World Wide Web enables students to locate information shared among experts (**Hill & Hannafifin, 2001**), while the convenience of electronic mail and bulletin boards helps to promote communication among peers, teachers, scientists, and community members. However, while proponents have heralded the potential of technology, it may not facilitate the engagement and learning valued by the scientific community. However, most students also lacked prior experience using the Web to find, process, and interpret information identified and accessed during their inquiry activities. The 21st century skills and the competing perspectives on technology in supporting student learning, teaching and learning contexts in science education classrooms practices as well as the pedagogical framework were explored.

21st Century Skills

The term 21st century skills are a broadly encompassing concept referring to multiple skills or subcategories of skills. 21st century skills or 21st century competences is an overarching concept for the knowledge, skills and dispositions that citizens need to be able to contribute to the knowledge society. According to **Scott (2015)** 21st century skills is the knowledge, skills and attitudes necessary to be competitive in the twenty-first century workforce, participate appropriately in an increasingly diverse society, use new technologies and cope with rapidly changing workplaces. **Chalkiadaki (2018)** views 21st century skills as encompassing a broad range of skill sets and professional attributes, including: creativity, divergent thinking, critical thinking, team working (especially in heterogeneous groups), work autonomy, developed cognitive and interpersonal skills, social and civic competences, responsible national and global citizenship, consciousness of interdependence, acceptance and understanding of diversity, recognition and development of personal attributes, interactive use of tools, communication in mother tongue and foreign languages, mathematical and science competence, digital competence, sense of initiative and entrepreneurship, accountability, leadership, cultural awareness and expression, physical well-being. The 21st century, unlike any other period in human history, is characterized by the proliferation of technologies. The acceleration of technological advancement has made digital illiteracies essential for people in this information age. Technology supports the learning of other 21st century skills, including critical thinking and problem solving; communication and collaboration; and creativity and innovation. One of the essential 21st-century skill that builds students' communication and decision-making skills and their ability to contribute ideas is the inquiry-based learning (IBL) used for an effective 21st-century education. Therefore, an effective teacher must master the professional skills necessary to deliver a high-quality 21st-century education to their students.

Inquiry-Based Learning (IBL)

Inquiry-based Learning (IBL) is an educational approach that puts students at the center of their learning. Instead of being passive recipients of the teacher's knowledge, students take an active role in their educations by asking questions, conducting research, and creating arguments based upon the evidence. Through active inquiry and discovery, students become motivated to learn because they seek answers to questions that interest them rather than facts that have to be memorized. Also, Inquiry learning usually takes place in small cooperative learning groups, so students gain valuable experience working as team members. Inquiry learning is flexible enough to meet the needs of almost every teacher and learning scenario. IBL is learner-centered approach focusing on questioning, critical thinking and problem-solving. The learner is actively involved in formulating the question/naming a problem **(Chu et al., 2007; Harada & Yoshina, 2004).**

There are four types of inquiry that teachers can implement depending on their students' academic needs, experience, motivation, and ability to work independently or as collaborative teams. The four types of inquiry are limited inquiry, structured inquiry, guided inquiry, and open inquiry **(Banchi & Bell, 2008**). Limited inquiry is the least complex because it requires the teacher to construct and lead their students through the inquiry with a predetermined procedure and outcome. The next type of inquiry is the structured inquiry and is similar to the confirmation inquiry except that the final product is unknown. In a structured inquiry, the teacher prepares in advance all driving questions, sources, and explicit step-by-step instructions at each stage of the inquiry. Students will then think critically to arrive at an answer to the driving question. Students The open inquiry is the last type of inquiry. In this type of inquiry, students develop the driving question, formative and summative performance tasks, and locate all source evidence for the investigation. The teacher's role is to support their students along the way by acting as a guide or mentor. Open inquiry is the highest expression of student learning because the student is responsible for most of the heavy intellectual lifting. Students ask questions and find answers to the questions independently.

IBL is a pedagogical approach that engages learners actively in a knowledge-building process through the generation of answerable questions (**Harada & Yoshina, 2004**). This approach is related to problem- and project-based learning, in which learners adopt an inquiry mindset in addressing epistemic issues or in developing and completing projects with a relatively open-ended set of answers. Such pursuits can occur within the context of short-term (e.g., single session) engagement, or longer-term (e.g., semester-long) assignments. Such learning scenarios may be structured formally or informally, and take on myriad forms. The approach can be used in all subjects as the primary vehicle of instruction or an add-on to the traditional curriculum. This approach challenges traditional norms of the teacher-centered classroom in which the teacher is the source of all knowledge. In an inquiry-based classroom, the teacher is the guide on the side that facilitates and advises the students as they discover the answers to questions and construct their knowledge and understanding of the world. Students learn key scientific and life skills through inquiry-based learning. According to (**Edelson, 2001; Barab et al., 2000; Jackson, Krajcik, & Soloway, 2000; NRC, 2000; Mistler-Jackson & Songer, 2000)** inquiry-based learning also promotes through:

- Exploration. This allows students to investigate, design, imagine and explore, therefore developing curiosity, resilience and optimism.
- Argumentation and reasoning. This creates a safe and supportive environment for students to engage in discussion and debate. It promotes engagement in scientific discussion and

improves learning of scientific concepts. It encourages students to generate questions, formulate positions and make decisions.

- Positive attitudes to failure. The iterative and evaluative nature of many scientific problems means failure is an important part of the problem-solving process. A healthy attitude to failure encourages reflection, resilience and continual improvement.
- Manipulation of variables efficiently by visualizing scientific concepts dynamically and authentically
- Social interaction. This helps attention span and develops reasoning skills. Social interaction encourages students to generate their own ideas and critique in group discussions. It develops agency, ownership and engagement with student learning.

Technology and Student Learning Environment

Technology is in a constant state of advancement as we have advanced from slates to calculators and other useful tools. Technology is truly beneficial to the education process. It is not just for the furtherance or continuation of the education system, but is useful for the transformation of learners and all persons involved in the education system. Technology has played and continues to play an important role in the development and expansion of online education. The online teacher must use technology to enhance the course content. Technology provides educators essential tools to create **a** student-centered learning environment. The careful integration of technology into the classroom provides teachers and students with a limitless amount of educational resources that transform learning through inspiring creativity, collaboration, and critical thinking. Recent technology tools have really managed to take learning to the next level. These tools are capable of assisting learners in the collection and analysis of data. They help students release unlimited potentials that they may not have known that they possess. A few frameworks have been suggested to support student learning with technologies including scaffolding hypermedia to cultivate self-regulated learning, meta-cognitive scaffolds embedded in software for online inquiry and epistemic scaffolds to guide technology-supported inquiry (**Kim & Hannafin, 2011**). However, it was found that all teachers did not implement these frameworks in a consistent manner (**Kim & Hannafin, 2011**). As a result, there is significantly more interest in developing technology-enhanced learning environments that enhances inquiry-based learning in the science education classroom. This demonstrates the need to learn how to create technology-enhanced learning environments to enhance inquiry.

A Technology Enhanced Learning Environment (TELE) focuses on a student-centered model of education, integrates themes that are given real-life applicability through technologically supported delivery methods (**Hannafin & Land, 1997**). TELEs are educational environments in which students are immersed in "learning by doing" with an emphasis on learning, and less on the delivery. Based upon constructivist pedagogy TELEs provide learners with opportunities to explore their own interests in a flexible (e.g., tablets, iPads, PCs, SMART Board, Laptops, wikis, modules, virtual classrooms, etc.) and enriching manner. In turn, students utilize their background knowledge in synthesizing new information through the support of technology while acquiring new knowledge, skills, and attitudes. TELEs that are designed to support student-centered learning are rooted in five foundations: psychological, pedagogical, technological, cultural, and pragmatic (**Hannafin & Land, 1997**).

In order to have a successful student-centered, technology-enhanced learning environment, students must have the proper support in order to achieve "what is beyond their ability to accomplish independently (**Kim and Hannafin, 2011**). Scaffolding provides such a support and allows students to learn within their zone of proximal development. Once the student has become more capable, the external support that scaffolding provides can lessen and instead the student can rely on internal support. **Hill and Hannafin (2001**) classify TELE scaffolds for student-centered learning into four types:

i. Conceptual scaffolds: Conceptual scaffolds allow learners to make connections between concepts and visualize and prioritize what is important. Conceptual scaffolds can be teacher-generated or learner-generated. In a technology-enhanced learning environment, conceptual scaffolds allow learners to…
ii. Meta-cognitive scaffolds: Meta-cognitive scaffolds provide a support for learners to evaluate, assess and reflect on their current knowledge and what to do as they learn.
iii. Procedural scaffolds- Procedural scaffolds assist learners in utilizing resources in order to maximize productivity. This can be in the form of navigational maps found on Web pages, frequently asked questions (FAQs), and trouble-shooting functions built into software.
iv. Strategic scaffolds- Strategic scaffolds provide the learner with an alternative method to carrying out a task. Such scaffolds can provide the learner with an expert to suggest the next step in their learning, or providing the learner with a collaborative environment where they can pose questions that will be answered by others.

Teaching and Learning contexts in Science Education Classrooms Practices

In an online environment, the role of the teacher changes from "the sage on the stage" to "guide on the side". Such new roles for online instructors require training and support. Faculty training and support is a key component of quality online education. Some case studies of faculty development programs indicate that such programs can have positive impact on instructors' transition from teaching in a face-to-face to an online setting. Participants' satisfaction towards the learning environment is a critical factor in online learning (**Andreatta, 2003**). The studies by **Klinger (2003**), **Motiwalla and Tello (2000), and Young and Norgard (2006)** reported that most participants were satisfied with the online courses and learning environments they had gone through. However, **Lauren, Jennifer, and Marguerite (2004)** in comparing participants' satisfaction with face-to-face courses and online courses reported that generally participants reported higher satisfaction with face-to-face courses. **Gallo (2007)** and **Strachota (2003)** reported that characteristics, such as gender, age and computer skills could influence students' satisfaction with online courses. On the other hand, there are studies that reported otherwise (**Hong, 2002; Hong et al., 2003**). Furthermore, **Motiwalla and Tello (2000), Sher (2004), and Young and Norgard (2006)** also reported that interpersonal interactions and positive feedbacks by instructors impacted positively on participants' satisfaction with online courses. **Andreatta (2003)** believed that feedbacks with affective components supported students' motivation which in turn resulted in higher satisfaction. However, investigations on the relationships between participants' learning styles and satisfactions with online courses did not yield clear results (**Hong, 2002; Klinger, 2003**).

Contextual teaching and learning of science education is based on situated cognition research which has found that constructivist processes such as critical thinking, inquiry learning, and problem solving should be situated in relevant physical, intellectual, and social contexts (**Brown, 2000; Cavallo, Miller, & Saunders, 2002)**. Contextual teaching and learning is consistent with a constructivist approach for the teaching of science education in schools (**Bentley, Ebert, & Ebert, 2000)**. The contextual teaching and learning approach anchors teaching and learning in students' diverse life contexts and prepares students for learning in the complex environments they will encounter in their future careers. Contextual teaching and learning is a grassroots initiative that has emerged from teachers' efforts to build upon situated-cognition research and integrate into one approach a number of validated strategies that are too often employed independently of one another. Contextual teaching and learning strategies include (1) inquiry learning, (2) problem-based learning, (3) cooperative learning, (4) project-based learning, and (5) authentic assessment. In order for these contextual teaching and learning strategies to be used effectively, they should be used with other commonly accepted good teaching practices such as promoting self-regulated learning and addressing student diversity when teaching (**Chiappetta & Koballa, 2002**). Contextual teaching and learning is a constructivist approach to learning in that it focuses on knowledge that is highly contextualized and relevant to students (**Johnson, 2002; Morrell, 2003**). Contextual teaching and learning science emphasizes using concepts and process skills in realworld contexts that are relevant to students from diverse backgrounds. This approach "motivates students to make connections between knowledge and its applications to their lives. Contextual teaching and learning is not a cookbook approach to teaching science. Instead, its component strategies provide a set of integrated tools that science teachers can use to instruct effectively and to address controversial yet fundamentally important issues that may be raised in their classrooms teaching and learning practices.

Pedagogy and Technology for Online Education

An effective online pedagogy is one that emphasizes student-centered learning and employs active learning activities. The learner must engage with their learning (i.e., environment) not only in a manner that connects to their prior knowledge but also utilizes technological resources in an applicable and constructivist approach. This model encourages environments which promote sampling, discovering, manipulating, and investigating (**Hannafin & Land, 1997**). Interactivity and student presence are all essential in an effective online learning environment. **Bill Pelz (2009**) provides the following three principles of effective online pedagogy:

- Principle 1: Let the students do (most of) the work. The more time students spend engaged with the content, the more they will learn.
- Principle 2: Interactivity is the heart and soul of effective asynchronous learning.
- Principle 3: Strive for presence: social, cognitive, and teaching presence.

Several research studies have covered effective pedagogical strategies for online teaching. **Keeton (2004)** investigated effective online instructional practices based on a framework of effective teaching practices in face-to-face instruction in higher education. In this study, Keeton interviewed faculty in post secondary institutions and rated the effectiveness of online instructional strategies. These instructors gave higher ratings to online instructional strategies that "create an environment that supports and encourages inquiry", "broaden the learner's experience of the subject matter” and “elicit active and critical reflection by learners on their growing experience base on technology.

Technology-Enhanced Tools

Institutions of higher education have increasingly embraced online education, and the number of students enrolled in distance programs is rapidly rising in colleges and universities globally especially in Nigeria. In response to these changes in enrolment demands, many states, institutions and organizations have been working on strategic plans to implement online education. At the same time, misconceptions and myths related to the difficulty of teaching and learning online, technologies available to support online instruction, the support and compensation needed for high-quality instructors, and the needs of online students create challenges for such vision statements and planning documents. In part, this confusion swells as higher education explores dozens of e-learning technologies, such as electronic books, simulations, text messaging, podcasting, wikis and blogs, with new ones seeming to emerge each week. Navigating online education requires an understanding of the current state and the future direction of online teaching and learning. There are three assertions related to technology-enhanced tools for student learning through inquiry:

i. tools support mindful investigation of driving questions,
ii. tools serve as meta-cognitive scaffolds for building and revising scientific understanding,
iii. tools support collaborative construction of scientific knowledge.

i. Supporting Mindful Investigation

Mindful investigation is the requisite cognitive and social-learning processes involved in active knowledge construction. Through mindful engagement, technologies serve as students’ intellectual partners to support higher order thinking skills. In science education learning, the focus on inquiry activities through which students identify meaningful driving questions, explore resources, and generate solutions in response to the problems (**NRC, 2000**). Researchers have examined the use of technologies designed to transform learning both qualitatively and quantitatively (**Lajoie, 2000; Voithofer, 2005**) by scaffolding higher-order problem solving and critical thinking. According to advocates, cognitive tools (technologies, tangible or intangible, that enhance the cognitive powers of human beings during thinking, problem-solving, and learning) help students to invest their attention in, and spend time on, problem-solving processes. Despite successful applications of technology in science classrooms, research on students’ cognitive and social processes using technological tools has proven challenging. Research is needed to examine student problem-solving strategies during technology-enhanced inquiry, cognitive and social learning patterns associated with different characteristics (e.g., prior knowledge, self-regulation, and motivation), and the influence of different technological affordances of inquiry tools during problem-solving activities.

ii. Providing Meta-cognitive Scaffolds for Science Learning:

Meta-cognition has been characterized as thinking about thinking and has focused on students’ ability to monitor and regulate thinking and learning processes during inquiry activities. According to proponents, computer tools help students to confront and address scientific misconceptions needed to revise and reconstruct their understanding (**Linn et al. (2003**) propose four principles for designing inquiry tools to support students’ knowledge construction: “making thinking visible, making science accessible, helping students learn from each other, and promoting lifelong learning. They further argued that students naturally build “multiple conflicting ideas about virtually any scientific phenomenon due to their everyday experience, compounding evidence, and naive prior knowledge. In everyday classroom contexts, many factors influence classroom implementation (e.g., students' developmental readiness, teacher roles, teaching practices, classroom cultures, standardized tests, and administrative policies). Furthermore, meta-cognitive scaffolds embedded in inquiry tools are used in substantially different ways depending on situational factors as well as students' prior knowledge and intrinsic motivation. The same features (indexed activities, hints, or prompts) can serve distinctly different learning goals and activities. Some students may use such scaffolds as cognitive aids to attend to their scientific investigations, whereas other students may simply browse through structured activities and hints with little or no mindful engagement.

iii. Facilitating Collaborative Construction of Scientific Knowledge

Advocates have suggested that technologies support learning as social practice in inquiry-based science classrooms. Inquiry tools can cultivate dialectical learning processes through cooperation with more (and less) knowledgeable peers. More recently, researchers have scaffold students' social interaction with both human and Web-based resources (**Hoffman, Wu, Krajcik, & Soloway, 2003)**. Similar challenges and issues emerge during classroom-based, technology-enhanced science inquiry. We examine two critical areas in science education: (1) the teacher's role in technology-enhanced inquiry classes and (2) the impact of the teacher's inquiry knowledge, experience, and professional development in the use of technology to promote inquiry.

1. **Teacher Roles:** Teachers play pivotal roles in inquiry-oriented classes as they select and design tasks, facilitate student activities, and assess their work (**Keys & Bryan, 2001**). To interpret and promote these essential roles, researchers have stressed the need for examining relationships between teacher beliefs in learning and teaching, teacher roles and student learning, and their classroom practices (**Bryan, 2003**). Teachers are expected to be flexible to students' individual needs, unpredictable classroom situations, and alternative explanations (**Wallace, 2002). Crawford's (2000**) detailed study of a successful high school ecology teacher revealed that inquiry-based science education classes demand more from teachers than do traditional lecture or exploratory classes. The innovative, successful teacher in her study played multiple roles (motivator, diagnostician, guide, innovator, experimenter, researcher, modeler, mentor, collaborator, and learner) to support student-oriented inquiry practices. While these attributes are challenging to describe adequately, they may prove even more difficult for teachers to envision or apply in everyday classroom practice (**Anderson & Helms, 2001)**. Many researchers concur that the major barriers to classroom inquiry are teachers' lack of time, resources, and technical support, as well as pressure from administration regarding standardized testing. Anderson and Helms pinpointed several constraints that science teachers face in initiating and sustaining inquiry in their classrooms:
   - lack of time to design and teach both content and process knowledge about inquiry;
   - conflicts between the ideal standards and the realities of the science classes;
   - tensions between emerging teachers' roles in inquiry classes and the typical school culture;
   - the "preparation ethic," in which teachers feel responsible for making students ready for the next level;
   - the challenges of assisting students of different levels to focus on higher level problems.

However, few studies demonstrate ways to overcome challenges or address these constraints. Despite a wealth of research highlighting the importance of teachers' roles in inquiry classes, few have examined the teacher's role in implementing and supporting technology-enhanced tools in the classroom. Although many technology-enhanced inquiry tools have been proved successful in science classes when supported by teams of researchers, these implementations are often advanced under small-scale, optimized conditions. Even in optimal instances, when support is eventually reduced or withdrawn, researchers report significant breakdowns in implementation (**Kim & Stein, 2006; Schneider, Krajcik, & Blumenfeld, 2005**). The everyday realities of initiating and sustaining implementation are even more daunting as teachers attempt to integrate inquiry into classrooms largely unaided and independently (**Fishman & Krajcik, 2003**).

2. **Teacher Experience and Knowledge:** For science teachers, authentic, personal, and professional experience and knowledge of both doing inquiry and doing research have proven pivotal for facilitation of students' inquiry practices. Several researchers challenged reformbased efforts for their failure to account for practical knowledge (deeply personal, highly contextualized) and influenced by teaching experience (V**an Driel, Beijaard, & Verloop, 2001)**. Furthermore, **Mulholland and Wallace (2005**) suggested that teachers' pedagogical content knowledge requires the longitudinal development of experience as they transition from novices to experienced teachers. Similarly, knowledge of subject matter influences teachers' use of technology-enhanced inquiry tools. To link teacher inquiry knowledge and experience to their use of tools, researchers have explored various ways to enhance teachers' pedagogical content knowledge and influence classroom inquiry practices (**Flick & Bell, 2000**). Others have proposed approaches that help teachers to comprehend the nature of science and inquiry-based teaching [e.g., professional development distributed via online programs (**Harlen & Doubler, 2004)**]. We need stronger evidence of approaches that link teacher inquiry experiences and knowledge, such as those provided through professional development programs, with actual classroom science education teaching practices.
3. **Technology-Enhanced Classroom Environments:** The uses of technology, both by teachers to teach and do science and by students to learn and inquire about science, have become core approaches to promoting scientifically and technologically literate. Responding to advances and growing demands for technology integration, researchers have proposed a multitude of technology-enhanced inquiry-oriented approaches (**Barab & Luehmann, 2003; Kim & Hannafifin, 2004)**. Technological advances have yielded tremendous opportunities for transforming science learning and teaching: collecting and analyzing data, modeling, and communicating results; locating and representing information in dynamic and interactive ways; and increasing the numbers of and access to computers in schools (**Edelson, 2001**). Based upon such affordances, scientific inquiry tools can have both literacy and pedagogical impacts. In contrast to science classes where teachers explicitly prescribe procedures to follow and content to be studied from textbooks, technology-enhanced, student-centered classes provide students with flexible opportunities to manage their inquiry processes and monitor their progress.

2. Conclusion

In conclusion, scientific inquiry is a multifaceted process involving participatory learning activities and meaningful discourse. Research on technology-enhanced inquiry environments suggests that while computer-based tools offer considerable potential, technology per se is unlikely to support students' inquiry processes. Well-designed computer tools, coupled with scaffolding from experts, teachers, peers, and community members, can support students' thinking and learning about scientific content and processes. It is important, therefore, to better understand the relationships between and among factors likely to influence the use and effectiveness of technology tools during science inquiry. Given the interdependence among the multiple factors involved in technology-enhanced scientific inquiry, a more inclusive pedagogical framework for teaching and learning with tools is needed.

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