Inquiry and Uncertainty of Thinking: Education with Technology

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Abstract: This paper develops an argument regarding thinking, inquiry, uncertainty and subject in working with technology. This development serves the analysis of learning with technology and discusses the educational consequences of working with technology. Doing that, the paper discusses the influence of two main features of technological cognitive tools on the learner's inquiry: interactivity and dynamicity. It argues that interactivity and dynamicity of the technological cognitive tools support the learner in his or her interaction processes during inquiry to investigate uncertain situations. It also argues that technological cognitive tools can support the imagination processes of learners that facilitate the development of their knowledge about the subject matter, besides facilitating their problem-solving processes. These tools can enrich the interactions between the learners during their engagement with the subject matter. It is argued that technological cognitive tools can support the subject in dealing with the uncertainty in learning and thus enriches her or his experimenting identity. This support could be strengthened by taking care of the tool's design.

Résumé : Cet article développe un argument concernant la pensée, l'enquête, l'incertitude et le sujet en travaillant avec la technologie. Ce développement sert à l'analyse de l'apprentissage avec la technologie et discute des conséquences éducatives du travail avec la technologie. Ce faisant, l'article discute de l'influence de deux caractéristiques principales des outils cognitifs technologiques sur l'enquête de l'apprenant: l'interactivité et le dynamisme. Il soutient que l'interactivité et le dynamisme des outils cognitifs technologiques soutiennent l'apprenant dans ses processus d'interaction pendant l'enquête des situations incertaines. Il soutient également que les outils cognitifs technologiques peuvent soutenir les processus d'imagination des apprenants qui facilitent le développement de leurs connaissances sur les questions

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examinées, en plus de faciliter leurs processus de résolution de problèmes. Ces outils peuvent enrichir les interactions entre les apprenants lors de leur engagement avec les questions examinées. On soutient que les outils cognitifs technologiques peuvent aider le sujet à faire face à l'incertitude de l'apprentissage et ainsi enrichir son identité expérimentale. Ce support pourrait être renforcé si on tient compte de la conception de l'outil.

Introduction

Researchers emphasize inquiry as a method of exploration of ideas in the various disciplines (Gill, 2014). One of the theoretical frameworks that addressed the inquiry issue is that of Dewey. Deweyan thought and education consider inquiry, reflective thought, and uncertainty of thinking and knowledge as central issues to understand the subject's learning. This central place in Deweyan thought is taken because "inquiry, action—and education—work to expand and create meaning and growth, to challenge given forms of life, and to point towards the future. By means of thinking, we actively produce new meanings and possibilities, and, as a result, new risks and uncertainty" (D'Agnese, 2017, p. 75). Uncertainty characterizes experiences, where action to get rid of it has no warrant of success (Dewey, 1929, p. 223). This uncertainty in the process and the product of experiences indicate the need for means and tools that support the learner in her or his educational engagement to address the uncertainty. One type of such tool is the technological tool.

In the present research, we address the functions of technological tools in addressing uncertainty in students' work, especially in the context of exploration activities or investigative activities; addressed here as experimentation through inquiry. We will look at two main features of cognitive tools: interactivity and dynamicity. Addressing interactivity, we will discuss principally the interaction between the tool and the learner, while addressing dynamicity, we will discuss principally how the potentiality of the tool to express dynamic objects contributes to the learner's understanding of the scientific relations and objects. In addition, we will discuss other features of the technological tool; as those of supporting the subject's reflection and supporting the subject's imagination. We give special consideration to the design of the technological tool as it impacts the potentialities of the tool as the

previously mentioned ones. In the end, we give special consideration to the subject's identity in inquiry with technology.

Technological tools are becoming central learning means in the classroom (e.g., Abuzant et al., 2021; Lock et al., 2019; Miglani & Burch, 2019). Cognitive technological tools are used more and more by learners in their inquiry of the subject matter. Salomon, Perkins, and Globerson (1991) describe these tools as 'partners in cognition' as they extend human cognitive capabilities. They can be adapted or developed for or by the learner to support her or his engagement with the task and facilitate the critical and higher-order thinking of this engagement (Jonassen, 1996). In this way, they can enhance the cognitive power of the learner during learning and problem solving (Jonassen & Reeves, 1996). Enhancement here results in giving more or new power to the learner's inquiry, which results from the learner's ability to solve problems that she or he would have not solved without the cognitive tools (Kim & Reeves, 2007). This ability, and consequent power, is relevant in general to the learner's engagement in ongoing inquiry that results in knowledge construction.

Inquiry with technological cognitive tools is accompanied by the same factors and aspects as in the traditional inquiry, i.e. ambiguity, uncertainty and reflection. We elaborate on these issues below.

Inquiry with Technological Cognitive Tools

Researchers are concerned with inquiry as an educational method in learning (e.g., Daher, 2009; Singh & Hari Narayanan, 2021). Inquiry, including the one carried out with technological cognitive tools, starts in doubt or ambiguity. Dewey (1938), speaking of inquiry, argues that it begins with doubt and ends when the learner arrives at the conditions that result in the removal of doubt. This removal comes as a settlement of the doubt. The doubt and its settlement are almost similar in traditional and technological environments. The difference in settlement between these two environments is with the means by which the doubt is settled or is advancing towards settlement. In the two environments, the settlement of the doubt by inquiry comes through what Dewey calls 'Judgement': "judgment may be identified as the settled outcome of inquiry. It is concerned with the concluding objects that emerge from inquiry in their status of being conclusive." (Dewey, 1938, p. 120). We suggest that judgment is process and product, and as such, it makes inquiry logical and convincible, which results in the settled

outcome of the inquiry. Judgment, being a process, has an empirical aspect that links the means (methods) and tools employed and conclusions arrived at as their consequence, where this empirical aspect has the characteristics of the ambiguous (ibid, p. 9). In addition, judgment, as a product, represents the conclusiveness of inquiry and is the reasoning that points at this conclusiveness. Technological tools accompany the subject in the process of experimentation and can point at the path of judgment.

Experimentation is also central in educational thought as it is related to inquiry (Dewy, 1938), which makes inquiry related to the change of the environment. This change is due to the nature of the experimentation, where the experimentation processes involve generally a modification of existing conditions through actions as 'touch, the acts of pushing, pulling, pounding and manipulating', which support the subject to find out what things are (Dewy, 1938, p. 34). The previous processes of empirical inquiry, their counterparts, or different processes could be observed in the learner's working with technology. Utilizing technological cognitive tools, i.e. companions that support the knowledge construction of the subject matter, the learner modifies or changes the objects that are part of the subject matter. These modifications changes could be accomplished by the different affordances of technology, as manipulation and dragging. Below, we elaborate on these supportive potentialities of tools that facilitate the learner's inquiry, especially the settling of the uncertainties in this inquiry.

Researchers who studied the inquiry processes of students with technology have emphasized the functions and the potentialities of the tools, especially in facilitating the interactions between the learner and the technological tool (e.g., Sedig & Sumner, 2006), where these potentialities facilitate the cognitive processes of the learner during her or his inquiry with the technology. Sedig and Sumner (2006) described, under the name 'Task-based Interactions' some of these potentialities, naming the processes: Animating, annotating, chunking, composing, cutting, filtering, fragmenting, probing, and rearranging. They also described under the name 'repicturing' the two processes: Scoping and searching. Describing zooming; one of the interaction processes of the subject with technology, Sedig and Sumner (2006) wrote: "zooming brings learners closer to or further from the mathematical structure or concept they wish to analyze". They describe scoping as: "learners can dynamically adjust the scope of 4D polytopes to analyze their structures". Thus, when the technological tool accompanies the

learner in the zooming and scoping processes, she or he can have a different look at the object, which enables furthering the inquiry process and arriving at relations related to the object. These processes accompany the subject in settling the doubts encountered in the problem situation and which prompted the technology-based inquiry process. Processes, as zooming and scoping, empower the subject as learner of the content. In addition, these processes are more numerous when the learner is accompanied by the technological tool, as these tools are designed to include numerous potentialities for learning (Biancarosa & Griffiths, 2012).

The previous processes were processes related to science inquiry with technological tools. A second set of processes was described by Nassim (2018) as processes enabled by technological tools and enrich language learning: customize motion, record and upload voice narration or music, scan and import text. A third set of processes was suggested for the arts (Kirk & Pitches, 2013, p. 219): image editing, juxtaposition, transition and sound sourcing to construct both linear and non-linear reflective narratives. In the three fields, the processes not only help lessenning the uncertainties in problem solving and creating content, but also help maintain a creative problem solving or inquiry (Kirk & Pitches, 2013).

Reflection is another tool that empowers the subject as a learner of the content (Kassan & Green, 2018). Dewey (1933, p. 195) points at reflection as supporting overcoming situations of uncertainty, including situations of obscurity, doubt, conflict, or disturbance. This support enables the learner to transform uncertainty situations into ones that are clear, coherent, settled, and harmonious. Reflection is associated with the cycle of inquiry consisting of the 'previous evolved meaning', 'new evolved meaning' and 'further meaning'. D'Agnese (2017) comments on the role of reflection in this cycle, emphasizing that the activity of understanding cannot be stopped by the reflection process as it is an ongoing process itself, which means that when we reflect on the understanding activity, it 'has already gone forward' (p. 79). So, not only reflection does not stop the cycle of learning, but it helps it move further.

In addition, to advance in the cycle of inquiry we need imagination that helps makes the activity 'more than mechanical' (Dewey, 1930, p. 276). Imagination supports inquiry and reflection on this inquiry. Inquiry needs cognitive engagement, including critical and high order thinking, which could be facilitated by technological tools that provide assistive visual mediators. These

visual mediators support students' cognitive engagement with the scientific concepts (Stanney, & Salvendy, 1995; Swidan & Daher, 2019). Thus, technological cognitive tools serve primarily the cognitive engagement with the content. Reflection could act in the technological environment, as it acts in the traditional environment, to monitor the cognitive engagement and direct it. Imagination facilitates and enriches the various components and processes of the learner's inquiry.

Reflection can be performed in the technological environment as in the traditional one, and, at the same time, it can be encouraged by utilizing special technological tools. Two such tools are the ePortfolio and the blog. Truer and Jenson (2003) describe the ePortfolio as enabling life-long learning and promoting critical reflection. In addition, Roberts, Maor and Herrington (2016) describe the blog as encouraging learners' reflection. Moreover, the ePortfolio and the blog are expected to encourage the reflection of learners on their inquiry processes (von Konsky & Oliver, 2012; Roberts et al., 2016).

Inquiry is impacted by what lies at its basis. Dewey stresses that 'in general it may be said that the things which we take for granted without inquiry or reflection are just the things which determine our conscious thinking and decide our conclusions' (Dewey, 1930, p. 22). In working with technology, part of what affects our work is the design of the tool, the theory behind this design and the goals of this design. Specifically, when considering the technological tools' functions, part of what we can take for granted without inquiry lies in the design of the tool and the standards of this design.

Prieto, Magnuson, Dillenbourg and Saar (2017, p. 14) described their design of tools in order to encourage teachers' reflection upon their everyday practice. Their first attempt in using the reflection tool was through very detailed sensor data. Their second attempt was through paper prototypes, while their third attempt was through a web tool. They say that the sensor data was 'overly expensive to setup and time-consuming to reflect upon the everyday practice. The paper prototype had its advantages and disadvantages: "remembering to observe in the middle of the lesson was difficult, but quite easy to do just at the end of the lesson". The web tool enabled 'a quick reflection wrap-up of the lesson's learning experience'. The previous description of Prieto et al. (2017) justifies the influence of the design on the potentialities of the tool.

Prieto, Magnuson, Dillenbourg and Saar (2017) described the development of their design of reflection tools, as a consequence of their experiences with teachers who reflected on their everyday practice. Bednar, Cunningham, Duffy and Perry (1992) argue that instructional design needs to be theory-based; i.e. lying upon some theory of learning and/or cognition. They emphasize that effective design is possible as far as the developer has utilized reflexive awareness of the theory of learning underlying the design. This argument indicates that the theory is not sufficient for effective design, because to be effective the developer should utilize reflective awareness of the theory underlying the design. We claim that the relationship of the designer with the reflective awareness lies in two aspects related to the objects of reflection: the reflective doing of the designer; what can be called reflective designing, and the design of reflective tools, i.e. tools with which the subject(s) can reflect on learning or practice.

To achieve a deeper understanding of the role of theories that lie at the basis of technology design, we need to consider how theories affected the design of technological tools. The behaviorist theory influenced the design of one of the first technological cognitive tools known as 'drill and practice' (Weegar & Pacis, 2012). These technological tools were the main tools from the late 1970's to early 1980's (Leinonen, 2005) and were designed to reward students "through an encouraging comment before moving on to the next learning objective" (Shield, 2000, p. 71). Lebow (1993) describes the shift in values when one takes a constructive perspective, where traditional educational technology values are those of replicability, reliability, communication, and control while the constructivist values are those of collaboration, personal autonomy, generativity, reflectivity, active engagement, personal relevance, and pluralism. These values affected the design of cognitive tools as the spreadsheets, the manipulatives and GeoGebra (e.g., Takači, Stankov, & Milanovic, 2015). The shift towards social constructivism has emphasized the need for interaction in the technology-based environment. This need affected the design of social networking tools as the eportfolio and the blog. Later, it resulted in the design of educational platforms as Moodle and Edmodo. In these platforms, the interaction could happen in the group of learners who take advantage of the potentialities of the educational platform, as the post and response in the forum. These platforms also enable the interaction of the instructor and the learner in the forum or through a task.

In addition to the above, the design of technological tools could focus on one aspect of inquiry, as high order thinking, critical thinking, reflection or interaction. Appropriate design of technological tools would make thinking less bottomless (Garrison, 2009), as it would facilitate the accomplishment of specific functions that support thinking. Moreover, reflection-oriented tools, such as eportfolios and blogs (Tan & Loughlin, 2014), are expected to encourage the reflection of learners, while interaction-oriented tools, such as games (Minović, García-Peñalvo, & Kearney, 2016; Sánchez & Peris, 2015), are expected to encourage interaction between pairs or groups of students or with the tools as a technological participant. In addition, community-oriented tools as blogs and forums are expected to encourage the community processes of the participants as communication and alignment towards common decisions (Baya'a et al., 2019). The accompanying of the technological tool encourages the decrease of the uncertainty in the learning actions associated with learning the subject matter. This decrease comes, as argued above, as a consequence of the potentialities of the technological tools that include their interactivity and dynamicity. Below, we elaborate on the contribution of these two features to the learner's inquiry.

Interactivity of the Technological Tools

Verenikina (2010) discusses the meanings of a technological tool's interactivity, wondering whether this interactivity should be viewed as an attribute of the technological tool, or it involves also the participants in the educational discourse as the student and the teacher. Verenikina (2010) adopts the definition of interactivity of the technology as associated with the teacher: "it is the teacher who orchestrates the classroom learning environment by making everyday decisions on pedagogically appropriate interaction arrangements." (p. 20). The author describes two kinds of interactions enabled by this 'directed by the teacher interactivity'. The first is related to the interaction in a group of students and which is initiated and advanced by the teacher to encourage the students to 'co-construct their views'. The second is the 'digital interactivity' in which the student interacts with the technological tool as a result of the teacher's intention to use a computer as a tutor. From the previous description, three types of interactivity of the tool are inferred: interaction in the group of learners and which is facilitated by a technological tool, interaction in the group of learners-as-a-unit and the technological tool, and interaction

between the individual learner and the technological tool. All the three types facilitate the learner's inquiry and the settling of the ambiguity through this inquiry.

Gros and García-Peñalvo (2016), in describing the role played by the interactivity of technology in students' advancement of knowledge, described the participants of these interactions: learners, teachers, and resources. They argue that the interactions between the three participants result from the critical dialogues and inquiries and result in knowledge that emerges from the bottom-up connection of personal knowledge networks.

D'Agnese (2017) stresses that we must conceive education "not so much as the attempt to master experience but as the means to create new, unpredictable experience by creating new points of interactions in our relationship with the environment" (p. 75). Technological cognitive tools create new points of interaction in our relationship with the environment, which supports us in our inquiry of the world and the subject matter. These points of interaction make inquiry possible as they enable visual and dynamic encounter between the subject and the content, which contribute to the lessening of the ambiguities that accompany the beginning and the procedure of inquiry and thus contribute to the settling of the points of uncertainty.

One type of interaction is called intervention, as in some points of the teacher's interactions with the students. Arzarello, Ferrara and Robutti (2012) stressed the importance of interaction of the teacher with the students who work in a technological environment. This interaction support the students in overcoming the technical difficulties besides those related to the exploration of relations and objects that populate the content. The teacher could also intervene to facilitate the sharing of ideas in the whole classroom (Daher et al., 2020). At the same time, the sharing of work with others encourages the students' critical thinking, which helps in settling the points of uncertainty in inquiry, as the discussion throughout the sharing clarifies points of ambiguity.

D'Agnese (2016, p. 75) argues that Dewey and Heidegger presume that we are always already embedded in the world, where such an embeddedness precedes knowledge and conscious control as they are grounded in experience. Technological tools have not changed the landscape concerning the features of our embeddedness in the world and its relationship with knowledge and control. This embeddedness lies at the heart of tools' design and is the base for the interaction of the learner and the teacher with the technological

tools. This again indicates the role of tools' design in impacting the subject's experiences.

Interaction with technology does not have advantages to students' inquiry as its sole product, for it could limit the inquiry of the learner. Westin (2009, p. 3) cautions that interactivity can be limiting: "Current digital interactivity enables only reactive behavior of the user but not an active choice and interpretation". This is not the case with cognitive tools, which enable the dynamicity of the interaction between the subject and the technological tool.

Dynamicity of the Technological Tools

Gros and García-Peñalvo (2016) highlights dynamicity as a characteristic of instructional design of the learning environments: "The learning environment should enable instructional elements designed as small, highly relevant content objects to be dynamically reorganized into a variety of pedagogical models. This dynamic reorganization of content into different pedagogical models creates a learning system that adapts to varying student needs" (p. 13). Gros et al., in the previous text, refer to the dynamicity of the learning environment, where such dynamicity allows the teacher and the student to effectively manage the learning process according to the student's needs. The teacher pushes towards specific interactions, while the students utilize these interactions in the inquiry process of content. Here, the constructivist pedagogical model encourages the active role of the student, while the social constructivist model encourages the active interaction between the students. The teacher can combine between different models in order to take advantage of their affordances.

Researchers also studied the dynamicity of cognitive tools. Arzarello, Ferrara and Robutti (2012) highlight dynamicity as an intrinsic feature of tools, where this feature could be present in the interface of the cognitive technological tool. They give examples on the components of this dynamicity (p. 20): "a geometric figure constructed in Dynamic Geometry Software (DGS); a graph of a surface traced through a symbolic software like Mathematica; a function represented using an i-Pad application" and on the processes of this dynamicity: "object dragging, object enlargement, object turning, object viewing from different perspectives". The previous objects are in the previous case mathematical, but they could be scientific as well. On the other hand, the previous processes are common for all the sciences. In addition, Naftaliev (2017) describes animations and models as dynamicity objects: "The

animations and models are simplifications that attempt to capture the essential features of the reality they describe" (p.33). Here, though Naftaliev is referring to mathematical objects, the objects she names are generic, meaning that they could be related to the different scientific contents.

Arzarello et al. (2012) emphasize that that dynamicity of the tool, or of the mathematical objects in the interface of the tool, supports the students' inquiry; specifically, through supporting the processes: exploring, discovering, conjecturing and validating or refuting the conjectures. The authors say that through such inquiry processes, dynamic representations allow cognitive affordances that may lessen the learner's cognitive load. In addition, the authors argue that though conjecturing using dynamic thinking is also possible without dynamic technology, this dynamic technology gives students new possibilities for developing transformational and dynamic reasoning at the school and university levels (p. 21). When reflection accompanies this transformational dynamic reasoning, it supports the lessening of the uncertainty of learning and thinking. The need for reflection is stressed by Maddux and Donnett (2015) who argue: "Reflection is where old thoughts are either put to rest or rehabilitated and where a certain quality of indicativeness in our experience—a sense that what we encounter in uncertain moments of existence implies more than bare perception—allows us to examine what is both sound and unsound in our current knowledge" (p. 64). This support of reflection allows to proceed to settle the uncertainties in inquiry.

The Subject's Identity in Inquiry with Technology

D'Agnese (2017) discusses the relationship between consciousness and experience, arguing that, on the one hand, consciousness springs from experience and, on the other hand, consciousness re-frames and re-establishes experience. This argument regarding the interaction of consciousness with experience fits the technological context in which points of interaction between consciousness and experience are facilitated by the cognitive technological tools that visually and dynamically mediate the relationship between consciousness and experience. This mediation enriches the identity of the learner as experimenter. This enriching of the experimenter identity is also mediated by the interaction between the subjects themselves, after or during working with the technological tools. The teacher also mediates the identity of the learner as

experimenter. Arzarello et al. (2012) pointed at the whole class interaction, after working with technology, as opening cognitive space in which strategies and solutions are shared, which contributes to students' inquiry. In this interaction, the teacher mediates between the learner and the construction of knowledge, which enriches the learner's identity as experimenter in the technological environment.

Naftaliev (2017) points out that the subjects, as they learn the content through interactive curriculum materials, such as interactive textbooks, experiment identity. These curriculum materials color the subjects' identity with inquiry as way of experimentation: "Using technology … provides a captivating, engaging tool which encourages learners to explore mathematical models and to devise their own models as suggested by the learning sequence" (p. 32). During this exploration of these models, the interactive curriculum creates new paths for learners to develop their knowledge of the subject matter, which contributes to their experimenting identity, supporting them in settling the uncertainty in the experimenting interactions.

As the subject works with technology to learn the content and solve problems related to this content, this mode of learning becomes habit for the subject, and thus becomes part of the subject's identity. Being a habit, the subject will utilize technological cognitive tools in order to solve content problems, especially difficult ones. This will be essentially the case, especially when the technological tool's functions serve the learning goals of the learner. Naftaliev (2017) describes three functions existent in interactive diagrams, which are one type of technological tools: illustrating, elaborating, and guiding. These features, as they enable the construction of knowledge, encourage reorganization of habits to become a mode of inquiry. When this mode of inquiry becomes a habit, it enters consciousness and, subsequently, becomes intelligently controlled by the subject (Semetsky, 2008, p. 90).

Le Rossignol (2018) discusses the subject's identity in working with digital storyworlds. She talks about leap of imagination and experiential immersion as characterizing the moving of the subject from passive to active participant in learning in the storyworlds digital environment. The subject engages in imagination that plays the role of agency in exploring uncertainties and possibilities.

Reflection in or about the learning experience with technology also affects the subject's identity as experimenter. Quay and Seaman (2016) argue that the reflective experience changes being,

saying that as reflection changes learning it changes the self (p. 45). The change to identity in working with technological tools comes through the multiple interactions between the subjects themselves, as well as between the subject(s) and the technological tool. Through these interactions, the subject becomes an experimenter with tools, and thus develops an ability to deal with the uncertainty of thinking.

To conclude, in the present paper, we attempted to discuss the contribution of the technological tools to the lessening of ambiguities and uncertainties in learning. We argued that the tool's interactivity and dynamicity are part of the tool's potentiality as means to lessen the ambiguities and uncertainties in learning. We also argued that the subject's reflection on her or his learning processes contribute to the lessening of the ambiguities and uncertainties in learning, where this reflection can be provided and enriched by technological tools. The same previous argument applies to imagination, where the visuality provided by the technological tool, especially by the cognitive tool, contributes to the subject's imagination. As the technological tool accompanies the subject in her or his experimenting of the content, this experimenting becomes part of the identity of the subject.

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