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The pandemic experience has, to date, been inspiring, illuminating, and challenging for the Canadian Journal of Learning and Technology editors, authors, and reviewers. We are ready to present the following overview of issue 48(1).

The introductory segments of this issue take a broad view of learning and technology, both with a cautionary tale. The Notes article, ***Learning, Technology, and Technique,*** is written by the esteemed **Dr. Jon Dron**, Professor, Athabasca University**.** He opens our eyes to the comprehensiveness of technology applications. He does so because "technology of learning almost always involves the co-participation of countless others, notably learners themselves but also the creators of systems, artifacts, tools, and environments with and in which it occurs." I encourage you to read this treatise about the collaborative integration of multiple areas of expertise, woven together into tapestries of engaging transformational experiences. It may be that "almost always" in the quote above will become "should" or just "always."

This issue's book review covers **Audrey Watters'** publication ***Teaching Machines: The History of Personalized Learning,*** MIT Press. Book reviewer Ms. Irina Tursunkulova, graduate student at the University of British Columbia, identifies the value of this book's timely overview of teaching machines. In our current post-pandemic awareness of the strengths and benefits of technology for learning, this book reminds us of the importance of history and research evidence. Watters' narrative provides an explanation as to why the so-called "new idea" of personalized learning, offered by current educational technology companies and industries, actually dates back a century to the 1920s, and has a history of trials and failures about which we should all be aware.

Most academic articles published in CJLT are original work that includes empirical evidence. Of the five articles published in this issue, four of these articles report results from a range of education technology applications. The fifth article provides a systematic review of the literature from publications that address learning environment characteristics during COVID-19.

Amélie Lemieux, Université de Montréal, Canada and **Stephanie Mason**, Mount Saint Vincent University, Canada, offer evidence that participant-generated documentation presents relational understandings that impact literacies. Our first article, titled ***When in Doubt, Map it Out: Teachers' Digital Storytelling Researched through Documentation***, outlines how technology can influence teacher practice and development. Using *Scratch* and multimodal dimensions from music to animation and movement, learning can move into a more creative dimension of digital storytelling, challenging the idea of 'simply doing' as the main process of technology implementation.

From digital stories to digital visualization, article two addresses ***A Typology Proposition of Effective Visual Programming Practices.*** **Simon Parent**, Université de Montréal, Canada, presents the results of a multiple-case study. The study uses a typology of effective visual programming practices with primary school students. Results from empirical data about the use of the "Deviens un maître NAO" device, which allows students to mobilize their skills by programming a humanoid robot called NAO, suggest significant pedagogical potential for the development of textbooks or pedagogical guides for primary school students or teachers.

Sustainability and Scalability of Digital Tools for Learning explores factors that increase the likelihood successful implementation of ABRACADABRA, a technology-based approach to teaching and learning literacy. **Larysa Lysenko, Philip C. Abrami,** and **C. Anne Wade**, Concordia University, Canada, present an approach that explains a portion of variance in the self-reported intent to use the software. The most significant contributions come from policies, professional development, and students. These findings are useful in the context of low- and medium-income countries where, currently, no research-proven principles exist to build sustainable and scalable educational interventions.

Interactive problem-solving is the topic of article four. **Margarida Romero,** Université Côte d'Azur, France, and **Sylvie Barma,** Université Laval, Canada, have penned ***Analysing an Interactive Problem-Solving Task Through the Lens of Double Stimulation.*** This study considers the materialistic nature of double stimulation using the CreaCube interactive robotic problem-solving task. The task requires participants to build interactive robotic modules that enable the artifact to move from an initial position to a predetermined final position. Double stimulation is explained in relation to the artifactual interactive affordances of educational robotics.

Investigating Characteristics of Learning Environments During the COVID-19 Pandemic: A Systematic Review by **Abdullah Al-Ansi***,* Universitas of Mahammadiyah Yogyakarta, Indonesia, is our fifth article. This paper investigates the accelerated education transition from traditional learning environments through online learning environments to social, innovative learning environments. Trends include the use of cloud platforms, massive open online courses, digital learning management systems, open educational resources, open educational practices, m-learning, and social network applications.

Our sincere thanks to the authors represented here and the reviewers responsible for supporting the quality of this journal.

L'expérience de la pandémie a été, jusqu'à présent, un voyage inspirant, éclairant et stimulant pour les rédacteurs, auteurs et réviseurs de la Revue canadienne de l'apprentissage et des technologies. Nous sommes heureux de vous présenter l'aperçu suivant du numéro 48(1).

Les textes d'introduction de ce numéro adoptent un point de vue le plus large possible sur l'apprentissage et la technologie, avec dans les deux cas une mise en garde. Les Notes, intitulées ***Learning, Technology, and Technique***, est rédigé par l'éminent **Dr. Jon Dron**, professeur à l'Université Athabasca. Il nous ouvre les yeux sur la complexité des applications technologiques parce que "la technologie de l'apprentissage implique presque toujours la co-participation de nombreuses autres personnes, notamment les apprenants eux-mêmes, mais aussi les créateurs de systèmes, d'artefacts, d'outils et d'environnements avec et dans lesquels elle se déploie". Je vous encourage à lire ce texte sur l'intégration collaborative de multiples domaines d'expertise, tissés ensemble dans des expériences de transformation engageantes. Il se peut que le "presque toujours" de la citation ci-dessus devienne "devrait" ou simplement "toujours".

La recension de livre de ce numéro porte sur l'ouvrage d'**Audrey Watters** intitulé ***Teaching Machines : The History of Personalized Learning***, publié par MIT Press. La rédactrice de la recension, Mme Irina Tursunkulova, étudiante aux études gradués de l'Université de la Colombie-Britannique, souligne la pertinence de ce livre qui donne un aperçu opportun des machines à enseigner. Dans notre prise de conscience post-pandémique actuelle des forces et des avantages de la technologie pour l'apprentissage, ce livre nous rappelle l'importance de l'histoire et des résultats de la recherche. Selon la critique Tursunkulova, le récit de Watters explique pourquoi la soi-disant "nouvelle idée" de l'apprentissage personnalisé, proposée par les entreprises et industries de technologie éducative actuelles, remonte en réalité à un siècle, aux années 1920, et à une histoire d'essais et d'erreurs dont nous devrions tous être conscients.

La plupart des articles scientifiques publiés dans le RCAT sont des travaux originaux qui reposent sur des données empiriques. Parmi les cinq articles publiés dans ce numéro, quatre d'entre eux font état de résultats provenant d'un éventail d'applications de la technologie éducative. Le cinquième article présente une revue systématique de la littérature des publications antérieures traitant des caractéristiques de l'environnement d'apprentissage pendant le COVID-19.

Amélie Lemieux, de l'Université de Montréal, Canada, et **Stephanie Mason**, de l'Université Mount Saint Vincent, Canada, présentent des résultats prouvant que la documentation générée par les participants, y compris la cartographie, présente des concepts relationnels ayant un impact sur les littératies. Dans notre premier article, intitulé **Cartographier pour comprendre : la mise en récit numérique documentée par des enseignants dans un cours de 2e cycle à l'université**, nous décrivons comment la technologie peut influencer la pratiques et le développement profesionnel des enseignants. En utilisant *Scratch* et des dimensions multimodales comme la musique, l'animation et le mouvement, l'apprentissage peut accéder à une forme plus créative de narration numérique, ce qui remet en question l'idée de "faire simplement" comme principal processus de mise en œuvre de la technologie.

Des histoires numériques à la visualisation numérique, le deuxième article traite d'une ***Proposition d'une typologie des pratiques effectives de programmation visuelle***. **Simon Parent**, de l'Université de Montréal, Canada, présente les résultats d'une étude de cas multiples reposant sur une typologie des pratiques efficaces de programmation visuelle avec des élèves du primaire. Les résultats issus de données empiriques sur l'utilisation du dispositif "Deviens un maître NAO", permettent aux élèves de mobiliser leurs compétences en programmant un robot humanoïde appelé NAO, et suggèrent un potentiel pédagogique important pour le développement de manuels ou de guides pédagogiques destinés aux élèves ou aux enseignants du primaire.

Durabilité et évolutivité des outils numériques d'apprentissage : ABRACADABRA au Kenya explore les facteurs qui augmentent les chances de réussite de la mise en œuvre d'ABRACADABRA, une approche basée sur la technologie pour l'enseignement et l'apprentissage de la literacy. **Larysa Lysenko, Philip C. Abrami et C. Anne Wade**, de l'Université Concordia, Canada, présentent une approche qui explique une partie de la variance dans l'intention autodéclarée d'utiliser le logiciel. Les contributions les plus significatives proviennent des politiques, du développement professionnel et des étudiants. Ces résultats sont utiles dans le contexte des pays à faible et moyen revenu où il n'existe pas de principes issus de la recherche pour construire des interventions éducatives durables et évolutives.

La résolution interactive de problèmes est le sujet du quatrième article. **Margarida Romero**, de l'Université Côte d'Azur, France, et **Sylvie Barma**, de l'Université Laval, Canada, ont rédigé ***Analyse d'une tâche interactive de résolution de problèmes sous l'angle de la double stimulation***. Cette étude porte sur la nature matérialiste de la double stimulation durant l'activité de la tâche de résolution de problèmes robotiques interactifs CreaCube. Cette tâche exige des participants qu'ils construisent des modules robotiques interactifs qui feront bouger l'artefact d'une position initiale à une position finale prédéterminée. La double stimulation est expliquée en relation avec les affordances interactives artefactuelles de la robotique éducative.

Enquêtes caractéristiques des environnements d'apprentissage pendant la pandémie de COVID-19 : Une revue systématique par **Abdullah Al-Ansi**, Universitas of Mahammadiyah Yogyakarta, Indonésie, est notre cinquième article. Cet article étudie la transition accélérée dans l'éducation, des environnements d'apprentissage traditionnels aux environnements d'apprentissage en ligne, en passant par les environnements d'apprentissage sociaux et innovants, ainsi que les dernières tendances de ce changement. Ces tendances comprennent l'utilisation de plateformes en nuage, de cours en ligne ouverts et massifs, de systèmes de gestion de l'apprentissage numérique, de ressources éducatives ouvertes, de pratiques éducatives ouvertes, de m-learning et d'applications de réseaux sociaux.

Nous remercions sincèrement les auteurs dont les travaux sont représentés dans ce numéro ainsi que les évaluateurs qui ont contribué à la qualité de cette revue.

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Learning, Technology, and Technique

Apprentissage, technologie et technique

***Jon Dron**, Athabasca University*

Abstract

To be human is to be a user, a creator, a participant, and a co-participant in a richly entangled tapestry of technologies – from computers to pedagogical methods - that make us who we are as much as our genes. The uses we make of technologies are themselves, nearly always, *also* technologies, techniques we add to the entangled mix to create new assemblies. The technology of greatest interest is thus not any of the technologies that form that assembly, but the assembly itself. Designated teachers are never alone in creating the assembly that teaches. The technology of learning almost always involves the co-participation of countless others, notably learners themselves but also the creators of systems, artifacts, tools, and environments with and in which it occurs. Using these foundations, this paper presents a framework for understanding the technological nature of learning and teaching, through which it is possible to explain and predict a wide range of phenomena, from the value of one-to-one tutorials, to the inadequacy of learning style theories as a basis for teaching, and to see education not as a machine made of methods, tools, and systems but as a complex, creative, emergent collective unfolding that both makes us, and is made of us.

Résumé

Être humain, c'est être un utilisateur, un créateur, un participant et un coparticipant dans une tapisserie richement emmêlée de technologies - des ordinateurs aux méthodes pédagogiques - qui font de nous ce que nous sommes autant que nos gènes. Les utilisations que nous faisons des technologies sont elles-mêmes, presque toujours, des technologies, des techniques que nous ajoutons au mélange emmêlé pour créer de nouveaux assemblages. La technologie la plus intéressante n'est donc pas l'une des technologies qui forment cet assemblage, mais l'assemblage lui-même. Les enseignants désignés ne sont jamais seuls à créer l'assemblage qui enseigne. La technologie de l'apprentissage implique presque toujours la coparticipation d'innombrables autres personnes, notamment les apprenants eux-mêmes, mais aussi les créateurs de systèmes, d'artefacts, d'outils et d'environnements avec et dans lesquels elle se produit. À partir de ces fondements, cet article présente un cadre permettant de comprendre la nature technologique de l'apprentissage et de l'enseignement, grâce auquel il est possible d'expliquer et de prévoir un large éventail de phénomènes, de la valeur des tutoriels individuels à l'inadéquation des théories sur les styles d'apprentissage en tant que base de l'enseignement, et de voir l'éducation non pas comme une machine faite de méthodes, d'outils et de systèmes, mais comme un déploiement collectif complexe, créatif et émergent qui nous fait et qui est fait de nous.

The Nature of Technology

The term *technology* is an ever-evolving fuzzy abstraction with multiple contested meanings. I do not have space to address even a fraction of these here but refer you to Dron (2022) for a fuller discussion. For the sake of clarity, I will, though, distinguish between the subset of technology better described as *tech* (typically the stuff with flashing lights and microchips) and *technology* itself (that includes the desks, legislation, and poetry). This is a paper about learning and *technology,* not just *tech,* though all that is true of technology is also true of tech.

The definition of *technology* used in this paper is 'the orchestration of phenomena to our use' (Arthur, 2009, loc 783-786), because it is more discriminatory and inclusive than most. Simplifying a little, technology is *the organization of stuff to do stuff*.

The stuff that is organized may be anything that exists or that we imagine exists in the world, from fire or metal to beliefs about how people learn or the presumed wishes of gods. It may be physical, conceptual, virtual, organizational, structural, procedural, material, immaterial, real or imaginary. There are as much technologies of prayer as there are of locomotion (Franklin, 1999, pp 8-9). Symphonies are technologies, too (Kelly, 2010, loc 5269). Some technologies, such as thinking in words or doing mental arithmetic are, quite literally, a part of us. They are cognitive gadgets (Heyes, 2019) we can organize to do stuff.

Technology can refer to processes, products of processes, or abstractions. For instance, writing (abstract) is a technology that I am using to write (verb) some writing (noun), that you are reading. I am also using an unimaginably vast number of other technologies to write this – words, transistors, concepts, grammatical rules, a chair, a screen, electricity, theories, screws, books, websites, metaphor, keyboard skills, and so on, all play a role.

Virtually all technologies are made of, are developed from, and exist in essential relation to other technologies (Arthur, 2009). Technologies evolve and take form through the orchestrated assembly of other technologies. *The stuff that is organized to do stuff almost always includes other stuff that is organized to do stuff*.

The boundaries that we choose to place around what we describe as a technology are critical: it is not only the parts of the assembly that matter but, most of all, how those parts are organized to do stuff. It is profoundly mistaken to use the most obvious part of the assembly as a synecdoche for the technology that actually matters. It makes no more sense to inquire into the effectiveness of computers in learning, say, than to inquire into the effectiveness of their power supplies. To understand the technology, we must look at the whole assembly, not just at its more obvious constituent parts.

Learning Technologies

Fawns (2022) describes pedagogies and technologies as inextricably entangled, while Anderson (2009) calls their relationship a dance. However, pedagogical methods and principles (*pedagogies*, for short) *are* kinds of technology, too, organizing stuff (subject matter, beliefs about learning, media, words, theories, and so forth) to do stuff (helping people to learn). Learning technologies may usefully be described as those that include pedagogies as part of their assembly.

A learning technology assembly is not just the product of those we label as teachers: we are all learning technologists. Whenever we organize stuff with the intent of learning (whether knowingly or not) then we are using pedagogies, so the assembly is a learning technology.

There are nearly always *many* teachers who contribute to the assembly other than those designated as such, from fellow students and textbook authors to timetablers and architects. The most important organizer of stuff is *always* the learner, but no one is a true autodidact: we always learn from, with, and through countless others. Learning technologies are deeply distributed, and every part of their assembly matters to the whole.

We often talk of *using* technologies but, usually, that use is *also* a technology. The stuff we do with the stuff that is organized to do stuff is usually *another* organization of stuff to do stuff. You and I may, for instance, both use the same technology of language, and even most of the same words, but what matters is how we organize the words: the technology we make, not the technologies we use in the making. We don't so much use technologies as *participate* in them, forming a part of the technology itself as it, in a very tangible sense, forms part of us as a physical or cognitive prosthesis.

Sometimes, our participation is pre-determined. For example, when we tell the time from a clock, or solve a quadratic equation, our participation is proscribed, assuming the technology is to serve its designated purpose. I call these **hard** technologies, for the same reasons that subject areas like science or math are typically referred to as *hard* disciplines. Hard technologies can be enacted correctly: we must play our correct roles in order for them to work. Rules and regulations are hard, as much as light switches. The hardness is a description not of the parts of the assembly, but of the rigidity of our roles in being a part of it.

Sometimes, our participation demands creativity or invention. For example, we might use a pencil and paper to produce any of an infinite possible variety of drawings or writing, and there are uncountably vast numbers of ways we could hold the pencil or vary the pressure on the paper. We fill the gaps it leaves for us in endlessly new ways with technique and content that will never, even in an infinite universe, repeat the same way again. This is without even allowing for the fact that a pencil can, like a screwdriver, have infinitely many other unprestatable uses, from a murder weapon to a hair grip, filling a potentially infinite range of adjacent possible empty niches (Kauffman, 2019). I call such technologies **soft** technologies, for the same reasons that subject areas like arts or humanities are described as *soft* disciplines. Soft technologies can be enacted well, or less well, but never correctly, because there are always unprestatably many ways they could be enacted differently. Again, the word 'soft' describes our participant role in the technology's enactment, not the pencil or paper per se.

It is virtually impossible to find any purely hard or soft technologies because:

1. Almost all technologies are assemblies of other technologies, soft and hard, so almost all fall on a continuous spectrum between the two.
2. All may be assembled with others to become softer or harder, so softness depends greatly upon where we choose to place the boundaries around the assembly.

A clock, used to tell the time, is hard but, if it is used for decorative purposes or as a door prop, then it may be much softer. Equally, a pencil and paper may become harder when assembled with a join-the-dots picture, or for technical drawing. There is no technology that cannot be softened or hardened by assembling it with others, thereby creating a *different* technology.

Some technologies, like the pencil, are inherently needy, useless without further orchestration, and so are inherently soft while others, like the clock used as a timepiece, are hard but can become softer through assembly. Again, it is how we participate that makes them softer or harder, not the innate qualities of the parts. To its author, a multiple-choice quiz may be a soft technology but, to a student, required to select one and only one possible answer, it may be very hard. The boundaries of the assembly, the phenomena that are orchestrated, and the uses to which it is put are very different for the teacher and for the student.

Hard technologies provide replicability, reliability and efficiency, but at a cost of flexibility. Soft technologies afford creativity, flexibility and adaptability, but they demand effort and skill. They are inconsistent, unreliable, and normally inefficient. Hard technologies are essential: they provide scaffolds that can lift us beyond what humans could do unaided, can reduce the need for cognitive or physical effort, and are almost always present to some extent in any assembly. However, they must be assembled with soft technologies if they are to be of any use or value. A learning management system (LMS), say, is built from nothing but hard, deterministic components, including hard pedagogical assumptions embedded in its design (Laanpere et al., 2004), but is useless until assembled with the (potentially softer) content provided by course designers and students. And, like all technologies, it can be and almost always is part of a larger assembly, including components like academic regulations, management procedures, or professional body requirements that may harden, as well as pedagogies and opportunities for dialogue that may soften.

Harder technologies tend to play a more structural and dominant (but, except in dominative technologies like rules, rarely deterministic) role in assemblies than softer technologies, which must adapt and conform to the constraints of what are, by definition, more rigid parts. This means that, while pedagogies are (to teachers) usually very soft technologies, they must be designed to fit into harder, more rigid technologies like timetables, fixed course lengths, curricula, assessment regulations, and so on. Pedagogies never, *ever* come first. Often, they are already built into harder elements of the learning process, from the design assumptions of LMSs, to textbook sequences, to scripted lesson plans. Although these may be assembled in ways that make them softer, it is usually simpler to be part of the existing machine than it is to create a new one. Strict assignment deadlines coded into an LMS can easily be subverted by allowing submissions using email, for example, but demand more cognitive effort and time from all involved and lose the reliability and consistency of the harder system.

Technologies and Technique

Soft technologies demand technique. By *technique* I mean the idiosyncratic, ever-varying, often creative ways in which we may organize stuff to do stuff. For example, there is hardness in handwriting, insofar as the letters and words must follow recognized patterns sufficiently well to be understood by others, and (for any given style) it is possible to attain something close to perfection in its execution. However, no two people ever have identical handwriting, and there are many acceptable styles of handwriting from which to choose.

Techniques are technologies, too, are as much a part of the assembly as any other. They can always be developed, practiced, and refined in the process becoming harder. The harder technologies we create can then become parts in a further assembly. For example, a musician practicing scales rarely does so to play scales well, but to play other music better.

'Perfect' technique is typically difficult or impossible to attain because there are unknowably limitless ways it could be enacted. Objectively poor technique (in the sense of not implementing or using harder technologies correctly) may still provide plenty of room for expression, communication, and meaning-making, as well as interpretation by other co-participants. As always, it is the assembly that matters, not the parts. Whether through their own technique or how they inspire their students to use their own, an untrained teacher with passion who cares about *what* they are teaching and *who* they are teaching can often teach better with poorer methods than a well-trained teacher who does not care. Technique fills the gaps between us as much as it fills the gaps left by hard technologies.

There is little or no correlation between effective learning and either the number of technologies we use or the technical precision with which they are orchestrated. However, having a larger range of tools (including more refined technique) affords more opportunities to do more. Every technology we create provides new adjacent possible empty niches (Kauffman, 2019) that can be filled with new ways of doing and being. Also, using harder technologies that do some of the work for us, be they pedagogical, digital, organizational, or whatever, frees us to do more, at a greater scale, with less cognitive effort.

Implications and Consequences

There are many consequences of seeing learning, teaching, and education as co-participative technological phenomena. This section provides some examples of a few of the more striking of these.

'Good' Ways of Teaching are Not that Good

Because around half of all teachers are, statistically, average or below average, softer pedagogies such as those in the constructivist or complexivist traditions that demand skillful technique are, on average, likely to be less successful in achieving hard, pre-stated outcomes than harder pedagogies such as those from objectivist traditions, that may provide stronger guidelines and prescriptive methods for teaching. This is indeed, on average, what we find (Hattie, 2013; de Bruyckere et al., 2015) and, for a skilled and talented teacher, active learning approaches are superior (Andrews et al., 2011). Equally, because all learning technologies are at least a little soft, it is quite possible to use weak methods well. There are countless great teachers using apparently terrible methods whose technique more than compensates. In fact, because designated teachers are only a fraction of the teachers involved in any learning transaction, successful learning may often occur even when they fail to turn up at all (Dron, in-press).

Bad Teaching Can be Successful

In-person universities are often able to employ many teachers who have never learned how to teach because much of the teaching is done by the institution itself. Selection procedures help to ensure competent self-teaching students, almost regardless of what kind of formal teaching occurs. Students are pulled from their own environments into an environment that broadcasts that its purpose is learning in every corner. They are surrounded by other students who provide role models, who share ideas, who discuss and debate. They have libraries, common rooms, curricula, credentials to aim for, timetables to follow, syllabi, and textbooks. Regulations determine norms, expectations, and constraints. Even the act of travelling to a lecture theatre for the purposes of learning a specific topic creates salience and value that may matter as much as the lecture itself. Teaching is profoundly distributed, and deeply embedded in the technologies of the institution.

The No-Significant-Difference Phenomenon is Inevitable

It is not at all surprising that a small subset of the technologies used to support learning make no significant difference to the learning outcomes (Pei & Wu, 2019), because 1) it is how the parts are assembled that makes the technology, not the parts themselves and 2) this can be done better or worse, no matter what components are involved. The skill (of all participants, especially including students) with which it is accomplished matters far more than the pieces that are assembled to accomplish it.

The Two-Sigma Problem Cannot be Solved

Few, if any, methods of teaching are as effective as one-to-one tutoring (Bloom, 1982), because one-to-one tutoring is not a method: it is a situation, in which any method at all could be used. The close relationship between student and tutor means that tutors can adapt their methods as needed to the individual. Even if better methods were devised that would meet Bloom's challenge, tutors could use them too.

Learning Styles Have No Value in Teaching

There is virtually no evidence that teaching to an individual's learning style has any value at all (Husmann & O'Loughlin, 2019). While it is clear that people do learn more effectively in different ways, it is likely because we learn methods of learning early in life, and we tend to prefer those that have (for whatever reason) previously been successful. We therefore preferentially practice them, improving our technique in using them. These are not learning styles but being-taught habits. But, even if there were any truth to any of the scores of contradictory learning styles theories, there are two big reasons it would have little value. Firstly, if it were true then it would also be true of teachers, and the chances that a teacher could teach using methods intended to cater for different learning styles with equal skill are close to zero: technique matters. Secondly, there will invariably be many other parts of the assembly that will have an equal or greater effect than methodical alignment with a learning style. But, even if it were effective, it would be unethical to act on it because we would be failing to teach students to learn using different methods, and the world in which they will become lifelong learners is not packaged to meet their learning styles. Being labelled as, say, an auditory learner would be little help if the objective were to learn to paint.

There is an Almost Total Absence of Replication Studies in Education

Only 0.13% of studies in top education journals are replication studies, most by the original researchers (Makel & Plucker, 2014). There is no need to despair of this because teaching is not a generalizable phenomenon that is susceptible to reductive research methods: it is a technology. Scientific theories and discoveries *may* certainly be parts of a technology assembly used for learning – they can be useful tools or phenomena in the orchestration - but only in orchestration with vastly many more parts that are not, any of which are likely to matter as much or more. Many of these are soft, so are dependent on the skills of the co-participants and never replicate. Replication is, for any non-trivial learning, therefore impossible. Moreover, the many co-participants involved are mutually affective, leading to unfathomably vast combinatorial complexity, rich in emergence and recursion, prone to chaotic chains of inter-reaction, so what we learn in trivial cases cannot be extrapolated to the non-trivial (Kauffman, 2019). Reductive scientific methods *may* be used to investigate behaviours of specific, well-defined hard technologies: the effects of changing the content of a SAT, for example. This may be useful in improving SATs, but that is all. In most cases, replication studies have no more value than any other story. Though methods, theories, models, and tools can provide vital scaffolds to support the process, teaching is a fundamentally human activity that cannot be reduced just to its technological parts. If we can better understand the technologies in which we co-participate, that we assemble with, through, and for others, if we can tell stories about them and share our discoveries, then we can create new adjacent possible empty niches for ourselves and others to build on. We and our co-participants will never assemble them in the same way twice, but we will all become better at doing so next time. This is the nature of education and the purpose of educational research. It is not just an inexact science. It is not a science at all. It is how we, collectively and individually, improve our toolset and our skills at using it.

Conclusion

Though technological in nature, education is not a machine. It is a process of learning to be part of a human society; of developing skills, values, and attitudes that help us to live, work, and play well with others; of being more capable of leading a rich and fulfilling life; of being useful contributors to our communities; of enabling us to learn continually and effectively throughout our lives. To achieve that we *do* need to learn hard skills, to engage with hard technologies, and to be parts of hard machines. Much of what we learn is concerned with attempting to create hard technologies within us, that we can assemble with others in order to achieve our purposes. Also, there is often much pleasure to be found in using even the most mechanical and mindless of technologies well, from sawing wood to doing the dishes. These are essential parts of the whole, without which education has no substance at all. However, these are means, not ends in themselves: parts of the assembly, not the reason for doing it. Soft technologies are what make the hard technologies matter, that lift the mechanical into spheres of imagination, value, engagement, and meaning. These are difficult to research, and impossible to define in terms of quantifiable objectives and outcomes, because they are always situated, always unique. Every assembly differs profoundly from every other that ever has been or will be.

The technologies around us are part of that cognition, too. From door handles that communicate their purpose (Norman, 1993) to smart systems that embed decision-making processes within their software or hardware, to all acts of communication with others through language, dance, music, and, indeed, every technology ever made, we share our cognition and discoveries with others. Our minds are extended through people and technologies in which we and others may participate (Clark, 2008), including those that are soft and unrepeatable.

Our technologies are what make human intelligence possible and are part of a fundamentally collective intelligence in which all of us (including the dead) may play a role. Learning is not just a phenomenon of the brain or body, but a means through which we and what we organize to do stuff become entangled with the stuff that *others* organize to do stuff. Our individual minds are made (in part) with technologies, and our technologies are embodiments (in part) of our minds. Technologies are not just extensions of our own minds, but they are how our minds become entangled in the minds of others. The educational process is thus not just an individual but a collective endeavour, a ratchet that lifts us all to greater heights, that connects us, that makes us who we are, and makes us more than we are.

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Teaching Machines: The History of Personalized Learning, 2021. By Audrey Watters. MIT Press. 328 pages. ISBN: 9780262045698

Reviewed by Irina Tursunkulova, *The University of British Columbia*

Introduction

Teaching Machines by journalist Audrey Watters blends the historical and political events of 1920-1960s in the United States and the changes in the K-12 school system, chronicling the rapid development of educational technology markets to show the inception and evolution of teaching machines. The author expresses her indignance towards Silicon Valley entrepreneurs who continue launching educational businesses, under the assumption that their "new" technological breakthrough will change the "stagnant" field of education technology. This book explicates how the "new idea" of personalized learning offered by current educational technology companies and industries dates back a century to the 1920s.

Pressey's Automatic Teacher

Watters begins her account of the history of teaching machines by describing the work of Sidney Pressey who, in the early 1920s and in cooperation with his wife Luella Cole, created almost 50 standardized tests, which were sold in the millions to schools as a new type of 'standardized' assessment. In part and influenced by this success, Pressey sought to build an Automatic Teacher, a machine that would provide learners with the answers instantaneously and free teachers from time consuming standardized test evaluation, an issue he had created previously.

After numerous unsuccessful attempts approaching manufacturers of typewriters, cash registers, scientific equipment, and publishers, as chronicled by Watters in 1929, Pressey teams up with a thriving W. M. Welch Manufacturing founded by a former superintendent. The letters and memoranda offered by Watters allows readers to witness the miscommunication between the manufacturing company and the scholar as they both worked toward refining and commercializing the Automatic Teacher. Pressey was so driven by the project that the lack of progress negatively impacted his mental health, and he had to spend months recovering in a mental hospital. Although it was hard for Pressey to give up the realization of the Automatic Teacher, eventually the work on the machine ended as did his marriage to Luella Cole, a prominent scholar who wrote several remarkable books on education.

The Creation of Teaching Machines: B. F. Skinner

Another prominent behavioural psychologist at the time, and indeed the focus of the book, is Burrhus Fredric Skinner who also became enthralled with the idea of constructing a teaching machine. Working at Harvard, Skinner started a new project aimed at building a teaching machine that would create a more personalized learning approach. As with many of Skinner's early behaviouristic experiments, this innovative idea was mostly oriented toward training students through positive reinforcement, something that built on his early and very famous work with training pigeons during WWII (Skinner, 1962) to guide missiles (though none ever did).

Almost a year after B. F. Skinner secured grants, hired a team of young scholars, and signed a contract with IBM for the development of a teaching machine, the Soviet Union launched Sputnik, the first satellite to be successfully launched into space, which escalated the Cold War between the Soviets and the Americans. American politicians and scholars found a connection between the launch of the artificial satellite and the science-oriented Soviet system of education, and viewed it as a potential threat to the supremacy of the American educational system for years to come. Skinner's teaching machine seemed to be the right project for that specific place and time.

Early in the teaching machine project, Skinner and his lab collaborated with IBM, focused on the creation of an arithmetical device that was an early version of a computer. Skinner's graduate student – Susan Meyer (Markle) – wrote what would be an incredibly important arithmetic program for IBM, which according to Markle (1964), would adjust lessons to learners' needs and challenge them to move forward. When the tension between Skinner and IBM escalated, Markle's rights, title, and interests were signed over to B. F. Skinner, although she had contributed to the development of early teaching machines.

When the collaboration between B. F. Skinner and IBM did not work out, Skinner looked for other potential business partners. Rheem Manufacturing Company was eventually contracted by Skinner to work on his teaching machine, that Skinner preferred to be named "Didak" or "Autodidak" in reference to the Greek word 'education' or 'self-education', which he knew would not be favored by teachers. Eventually, Rheem contractually agreed to officially name the device "Didak".

The Roanoke Experiment

While B. F. Skinner tried to take every opportunity to commercialize Didak, other researchers also worked to develop and implement programmed instruction. One of the most significant contributions in the field of teaching machines was made by Allen Calvin, a psychology professor at Hollins College, Virginia. Calvin received a generous grant from the Carnegie Foundation, of what would amount to over a half million US dollars by today's standards. These funds were used to conduct an experiment at Roanoke Public Schools; schools that were racially segregated at that time. The study focused on the progress of eighth grade students who were taught ninth grade algebra via programmed instruction. The results showed that the learners were able to cover an entire year of ninth grade content in one semester. Since all the instruction and assessment completed by the teaching machines proved to be successful in “The Roanoke Experiment”, it was agreed to expand the study. The subsequent study included 11 teachers and 900 students. However, due to the cost of the experiment, this time students used programmed textbooks. The programmed textbooks, as the machines, ensured that the learners acquired mathematical concepts at their own pace.

According to the Roanoke district superintendent, Edward Rushton, in addition to the favorable outcome of the experiment, teachers who participated in the study claimed that programmed instruction led to reconsidering their pedagogical practices. This second success created a chain reaction. Additional funds and a million-dollar grant from the Encyclopedia Britannica Films led to the hiring 700 staff. Nevertheless, only three months after the relocation to Palo Alto, the work on the project stopped due to disputes between the business-oriented Encyclopedia Britannica Films representatives and the academically oriented Hollins College scholars.

Teaching Machines: Technocratic Approaches

There were examples of successful collaboration between encyclopedia publishers and researchers. Teaching Machines Inc. (TMI) cofounded in 1959 by Lloyd Homme, who earlier worked under the supervision of B. F. Skinner, and James Evans, teamed up with one of the largest encyclopedia publishers – Grolier. The door-to-door sales approach was a familiar marketing tactic for educational technologies at the time, as encyclopedias were most often sold this way and there was an ongoing distrust of the public education system in the U.S. Unlike full sets of encyclopedias, the Min/Max machines required much less investment, and it became clear that door-to-door sales made TMI’s Min/Max successful. As its name suggests, Min/Max machines offered maximum learning in a minimum amount of time. The questions were constructed in a way that they gradually grew more complex as a learner proceeded through the program. Although the affordable machine promised that students would learn at their own pace, students could easily get bored by working on numerous, repetitive, and relatively simple tasks before they faced more challenging questions. Lloyd Homme was not the only person who, after working with B. F. Skinner, created a commercially successful teaching machine.

Ben Wyckoff, B.F. Skinner’s former student, left his behaviouristic views behind and created a more sophisticated machine that was considered an early prototype of a computer, which unlike the Min/Max machine, did not use paper. Grolier was interested in the program of the machine rather than commercializing a bulky and pricey device. Wyckoff’s film-tutor focused on teaching students how to read in a more engaging way as opposed to the simple “Question and Answer” format of teaching machines. A. A. Lumsdaine (1960) compared it to Norman Crowder’s AutoTutor. Crowder’s series of self-instructional manuals, TutorTexts, were adaptive to learners’ needs. Depending on the nature of the error made by the student in reading – a miscalculation or misunderstanding of the concept – the teaching machine would provide a suggestion about what page in the book to revisit to help correct the misunderstanding. From earlier machines that provided learners with the answers, this system focused on finding out *why* a learner made the mistake and what *approaches* needed to be utilized to master the task. Crowder seemed to have outgrown the ideas he worked on in Skinner's lab in 1954.

Watters claims that although Crowder called his version of programmed instruction "intrinsic", it was often described as "branching" (p. 141). In Skinner's model, students repeated the incorrect questions until getting them correct. Crowder's branching allowed more incorrect answers and provided alternative pathways, or branches, to arriving at the correct answer. Put another way, if Skinner's "linear" model required all students to go through the same set of questions, Crowder ensured that each student had alternate paths on the way to content acquisition. In his book entitled "Teaching Machine (and Learning Theory) Crisis", Pressey (1963) foresaw the crisis of the teaching machine movement, which he argued would fail due to the flaws of the behavioristic approach. The shift towards progressivism and a student-oriented approach led to the creation of more innovative programs and, in the 1980s, would be realized by more technologically complex descendants of the early teaching machines – computers.

Conclusion

At first sight there is an impression that every event described in the book revolves around B. F. Skinner. The irony of a one-man show is understandable as readers might not be familiar with the contribution of other scholars in the field of teaching machines and personalized education. In her blogpost "(Searching for) Norman A. Crowder and the AutoTutor" from 2018, Watters wrote that she was looking for Crowder's letter and papers. Apparently, researchers who tried to improve the field of personalized education were shadowed by their former employer – B. F. Skinner. Another topic that is omitted in the conversation is teachers. Although the book mentions that several scholars and journalists have viewed teachers as engineers and curators of the process of education, there have not been attempts made to train instructors for such purposes. For quite some time, researchers and technology companies have been dreaming about a utopia where there would be no practical use of teachers. This dream has not been reached despite the massive investments in technologies for education. Despite the promises of new and different technologies, much like teaching machines of the past, they have not offered solutions to the crisis in public education in the USA. As the outbreak of the global COVID-19 pandemic and social distancing made clear, we still need skilled and stress-resistant *human* teachers who can support and empathize with students.

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When in Doubt, Map it Out: Teachers' Digital Storytelling Researched through Documentation

Cartographier pour comprendre : la mise en récit numérique documentée par des enseignants dans un cours de 2e cycle à l'université

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Abstract

This article considers how documentation enriches literacies learning in higher education, specifically in a graduate course designed for language teachers. Building on a one-year research study with graduate students at a university in the Atlantic region of Canada, the authors demonstrate how participant-generated documentation, including cartography, presents relational understandings impacting literacies. Specifically, the authors look at a case study of two teachers enrolled in a graduate literacy course who crafted and designed digital stories using *Scratch* and used multimodal dimensions from music to animation and movement. Teachers' documentation challenges the idea that making is solely a question of doing, and considers instead long-lasting processes that influence teacher practice and development.

Keywords: making; teacher education; storytelling; cartography; multimodality

Résumé

Cet article démontre comment la documentation enrichit le concept de littératie à l'université, en particulier dans le contexte d'un cours élaboré pour des enseignants de langues. En s'appuyant sur des données issues d'un projet de recherche mené auprès d'étudiants du deuxième cycle dans une université des Maritimes, les autrices expliquent comment la cartographie produite par les participants présente des concepts relationnels qui déteignent sur la capacité à faire des liens, à comprendre, à réfléchir et à réagir. Pour ce faire, les autrices se penchent sur une étude de cas impliquant deux enseignantes inscrites dans un cours de deuxième cycle portant sur la littératie. Ces étudiantes ont composé un récit numérique à l'aide de *Scratch* et ont mobilisé des dimensions multimodales comme la musique, l'animation, et le mouvement. La documentation effectuée par les enseignantes interroge le concept voulant que la composition rime avec la simple action de « faire » et prend en considération des processus de réflexion importants en littératie, dans un contexte universitaire.

Mots-clé : production ; formation des maîtres ; mise en récit numérique ; cartographie ; multimodalité

Introduction

Attuning to Process in Literacies Research

There are 12 numbered steps in Jenny's[1] map, in colours ranging from a golden yellow to a pastel purple, with directional arrows connecting them suggesting non-linear pathways. The first step, labelled 'Emotions' reads, "I feel excited about our project", while the fifth step reads, "I have to clear my mind and do this logically." These bubbles and arrows form a diagram for a MakerMap, a relational cartography made as part of an assignment for a graduate-level literacy course Amélie Lemieux taught and developed at a Canadian university in the winter 2019 semester. The MakerMap acts as a participant-made documenting strategy to enliven entwined processes of making. This MakerMap in particular captured Jenny's situated entanglements with computer programming (or coding) during a joint project with a classmate, Grace, who was also new to this digital platform. In their processes, the graduate students, who were in-service teachers pursuing a graduate degree in literacy education, identified challenges in using unfamiliar technological resources in classroom settings. The following case study examines Jenny and Grace's literacies to inform how documenting literacy processes is useful for professional development and higher education research. Our research questions ask: What thoughts, feelings, and related reactions do teachers experience when they engage in maker literacies, and how can these be articulated through documentation? What are the implications of documentation for teachers' own classroom practice? This article delves into these questions, with attention to literacy processes of teachers enrolled in higher education courses.

Documenting Maker Literacy Practices and Processes: Challenges and Opportunities

Maker education refers to the active creation of material and technological artifacts based on shared knowledges and expertise (Peppler et al., 2016; Sheridan et al., 2020; Vossoughi & Bevan, 2014). Maker literacy practices are often deeply entangled with craftivism (Rowsell & Shillitoe, 2019) and relational ontologies (Keune & Peppler, 2019; Lemieux et al., 2020; Lemieux & Rowsell, 2020). In its expression of creative and communal drive, making allows students, teachers, and practitioners to take responsibility and be accountable for what they are creating, as the social aspect of maker education conditions and determines design, topics, and decision-making as part of student-led inquiries.

With making, learners engage in cross-disciplinary knowledge and minimize engagement in unidimensional pedagogical transmission models. In so doing, these processes nurture participative and collaborative practices. As collective learning unfolds, knowledges are expressed, bartered, generated,

[1] All participant names are pseudonyms.

and cross-pollinated rather than transmitted from expert to beginner (Tucker-Raymond et al., 2016). In that vein, makerspaces, as cross-disciplinary communities of practice (Halverson & Sheridan, 2014), encourage the implementation of overlapping complex engagement, among them sensory experimentation, digital play, and materially-oriented knowledge production. For instance, tinkering and trial-and-error experiences are effective for student engagement and skill development (Li & Todd, 2016), while discovery, real-time feedback, differentiated learning, and risk-taking are conducive to experiential learning and modelling (Li et al., 2019).

Making has received a lot of attention in the learning sciences, yet several barriers impede the general uptake of making in schools and limit teachers' capacities to document their forays into making as a classroom practice (Peppler & Bender, 2013). Makerspaces in school environments require substantial oversight, complicated by staffing limitations and restrictive web-related school policies (Li & Todd, 2016), often not conducive to documenting literacy practices. Since some curriculum restrictions hinder design models of making (Kafai et al., 2014), teachers are often discouraged to expand on (and thereby document) their making practices.

Attending to the documentation of literacy processes can help identify gaps in pedagogical strategies, such as a lack of resources, materials, and digital technology skills. Without this awareness, teachers may struggle to explore ideas and still meet classroom objectives and related program accountabilities (Sanders et al., 2019). Complacency sets making at odds with the traditional classroom structure. In parallel, ethical research conduct and data collection may perpetuate educational systems of thought that devalue underrepresented communities' knowledges (Peterson & Scharber, 2018; Vossoughi et al., 2016), and embed inequitable participation opportunities for digital literacy practices across schools (Dooley et al., 2016). With documentation comes the ability to generate widespread discussion and relational considerations that go beyond representational means (Albin-Clark, 2020). Recent and rapidly expanding technological change and information production demands the reexamination of traditional and static recording methods, and may even reveal new avenues for inquiry through emerging documentation practices.

Making fosters students' interests, supports academic development, and builds communities of practice (Vossoughi & Bevan, 2014); these outcomes depend, in part, on teachers' beliefs related to making and digital technologies. In some cases, teachers' negative attitudes towards maker literacy activities stem from the misconception that making is only possible with expensive technological tools (Cohen et al., 2018), which are misconstrued as being only accessible by the most affluent institutions and communities (Vee, 2017). Other teachers struggle to associate making approaches with their content areas (Cohen et al., 2018) or lack confidence in their own abilities to understand how making can inform their teaching practice (Rodriguez et al., 2018). Helping teachers become aware of these misconceptions and attitudes, by making them aware of their processes through documentation, is a step towards debunking these myths.

In this article we argue that teachers' engagement with their literacy processes through documentation is worthy of investigation as teachers first experience new skills that they may, in turn, teach their students. Without experiencing and documenting their learning through making, teachers may struggle to offer comprehensive, appropriate support to students undergoing activities such as coding. Into this gap fits documentation of these processes, which mollifies teachers' initial maker-related anxieties, substantiates ongoing professional development, and complements emerging transdisciplinary literacies research.

Why Does Research on Documentation for Professional Development Matter?

Coding generates new attitudes to literacy learning in classroom settings. Through coding, one experiences problem-solving through trial-and-error, decision-making, continuous feedback, troubleshooting, and complex elaboration (Resnick, 2017) based on engagement with online communities. Documenting processes about making and coding can shed light on how these analytical skills, trial-and-error, and decision-making operate relationally in education. Doing so provides evidence-based knowledge that can be used to understand how participant-generated relational processes can influence maker literacy practices and curriculum implementation. Through coding, situated technological understanding is extended towards broad social development (Resnick, 2017), affecting possibilities for transdisciplinary literacies uptake, representation, and digital innovation, among other areas (Furlong et al., 2019; Litts, 2015). In other words, we argue that newly acquired coding skills benefit teachers in understanding new relations to materialities borne out in process documentation. Reinscribing the worth of trial-and-error or tinkering approaches to learning puts teachers in a different role—a vulnerable one—with regards to coding. It is through participant-generated documentation, we argue, that teachers may realize how their literacy processes might alleviate some of the tensions and stresses associated with trying a new coding platform.

Yet reservations still exist in the form of teachers' perceptions and abilities related to coding practice (Wohlwend et al., 2016). Some teachers may not feel confident in their abilities to use technological tools (Cohen et al., 2018), while others may feel unsupported technologically in the schools where they work (Li et al., 2019). It appears the way forward is to recognize teachers' need to familiarize themselves with coding to allay their own fears and to offer meaningful support for students learning these skills. Education outcomes are affected by teachers who model supportive behaviours, resulting in greater communication and collaboration skills (Popat & Starkey, 2019). Long-lasting professional development opportunities can contribute to teachers' personal understanding and application of making principles in the classroom.

What Works in Teachers' Professional Development

For in-service teachers, coaching workshops and activities supporting self-confidence aid in fostering collaborative work, as do pedagogical beliefs in student-centred instruction (Li et al., 2019). Through observation and reflection (Desimone, 2009), modelling and experimentation (Li et al., 2019), and opportunities to experiment with maker-oriented strategies (Darling-Hammond et al., 2017), new approaches to classroom practice allow teachers to meaningfully explore emerging technologies.

Studies show that teachers' adjustments to their practice are more effective when their learning is grounded in the analysis of their learning processes through metacognitive awareness, all the while being supported through a professional learning community (Shulman & Shulman, 2004). However, little research has looked at how documentation practices, through multiple engagements with different documentation methods including metacognitive ones, might help teachers alleviate their anxieties related to making. Metacognitive practices, such as mapping, may prove useful in this area.

Metacognition consists of "knowledge or beliefs about what factors or variables act and interact in what ways to affect the course and outcome of cognitive enterprises" (Flavell, 1979, p. 907), and has been compartmentalized into general thinking and learning strategies, knowledge of tasks and their appropriate strategic applications, and knowledge of self and motivation (Flavell, 1979). It is not surprising, then, how students become more aware of their own thinking, as well as thinking in general, through metacognition (Pintrich, 2002). In literacy studies, students require time when reading not only to apply a particular strategy to increase their comprehension, but also to reflect on their thinking to assess the appropriateness of the strategy (Wilson & Bai, 2010).

For teachers, metacognition affects planning, monitoring, and evaluation by way of "an internal and active process of self-monitoring and self-awareness" (Beach et al., 2020, p. 397). The ongoing consideration of effects of their practices depict teachers' capacities for metacognitive understanding. However, research shows that effective teachers are ones who recognize they can continue to learn about teaching despite their existing abilities, while ineffective teachers tend to believe their teaching practices do not require improvement (Pressley, 2008). The metacognitive orientations of teachers, like others, may be an effect of personality, reflecting imagination, insight, thinking outside the box, and enjoying new experiences; "[o]penness to [e]xperience might be the nourishing source of metacognitive knowledge" (Ozturk, 2020, p. 42). Within the classroom, the applied benefits of metacognition pertain to teaching plans, behaviours, methods, performances, and reflective activities (Jiang et al., 2016). As Ozturk (2018) writes:

> Just like strategic learners, metacognitive teachers plan their instructional practices considering their goals, materials, and students' needs. They also continuously monitor and assess instruction's effectiveness in meeting goals and helping students to learn the content. (p. 32)

Awareness of students' responses and pedagogical flow prompts teachers to "make informed instructional adaptations or changes within the course of classes" (Ozturk, 2018, p. 32). While some schools have added metacognition to their repertoire of teachers' professional development, generally such aspects lack specific understanding and operate instead as additional features of existing programming (Hughes & Partida, 2020). Thus, there is immense pedagogical potential in engaging teachers in documenting their literacy practices and processes in dedicated classes to that end.

For decades, professional development for teachers aimed at documenting variations in satisfaction, attitudes, and innovation (Desimone, 2009), while separately but concurrently, information and communications technologies within classrooms have customarily served to enhance productivity and information presentation. When technologies are introduced in classrooms, there is an expectation that teachers will respond to these positively, and that these will foster teacher efficiency and student engagement. However, in practice, this is not always the case. Much research evidence further points to successful teacher professional development when they engage in open understandings of a subject by exploring, troubleshooting, implementing concepts, and looking towards improving what they have learned, which, to us, speaks to the ongoing need to document maker literacy practices. An effective way for teachers to consider integrating coding in their classes, for instance, is to try coding themselves through accessible programs because active learning engages teachers in similar learning designs and styles they will expect of students (Darling-Hammond et al., 2017). This is one of the reasons why a few teachers in this class experimented with coding as a novel activity as part of Lemieux's research.

Documenting one's learning can take many forms, crossing the disciplinary boundaries of the arts, visual imagery, graphic capture, and other means of visual recording (Mulcaster, 2017). In this study, we present a MakerMaps methodology. A MakerMap is a participant-generated record of relational engagements in making, deriving from a larger mapping methodology used in the arts and literacy studies (White & Lemieux, 2017). Constructing MakerMaps to document their learning when engaging in literacy processes allows teachers to conceptualize their knowledge to the benefit of their and other teachers' professional development and practice. It is for this reason that we focus our energies in this article on MakerMaps as accessible modes for charting reflection and understanding in meaningful ways, to document teachers' education, and grow the field of maker literacies research. This process can, in turn, reduce barriers to incorporating coding in the classroom. With these goals in mind, the subjects of our case study, Jenny and Grace, document their learning through MakerMaps illuminates the challenges and rewards of making practice for their development as teachers, as maker-teachers, and as maker-teachers of students.

Research Design

This case study explores the experiences Jenny and Grace encountered during a graduate-level literacy class developed by Amélie Lemieux at a Canadian university in the 2019 winter semester. We selected a case study approach because the teachers' encounters with making process were contained in a bounded system (Merriam, 2009) of professional development instruction, where data collection ended with the conclusion of the course. Jenny and Grace were among the 12 in-service teachers in the class introduced to multimodal literacies constructed from reimagined traditional writing, reading, and listening skills (Pahl & Rowsell, 2010). Time in class included six 3-hour workshops to support project creation and design, producing projects involving coding, storyboard and comic design, video editing, and digital art. Students created a lesson plan, artifacts (material and digital), and generated a visual map (or MakerMap) of their responses to making using a mapping software called Inspiration. Students also produced written commentaries to accompany their MakerMaps. Amélie took ethnographic field notes following the sessions, and arranged for a videographer to record three separate sessions of two hours each. Jenny and Grace consented to interviews about their design experiences and were the only students in the class attempting projects that required the use of coding. Grace and Jenny used *Scratch,* an example of an online, free-to-use, accessible computer programming software that both youth and adults can use to generate and gain input into games, animated stories, and interactive artwork. MakerMaps and artifacts consisted of both course materials and research data. Field notes, session recordings, and interviews were for research purposes only. MakerMaps, MakerMap commentaries, interviews (and interview transcripts), and digital artifacts (Scratch compositions) were primary data sources. Data were analyzed qualitatively, using codes generated by inductive thematic analysis.

MakerMap Methodology

The MakerMap methodology consisted of teachers:

(1) Writing down, on a sheet of paper, their reactions and thoughts as they were making their composition. These could include boredom, excitement, anxieties, and so on;

(2) Ranking each reaction by level of importance (1 being a barely perceptible moment; 4 being a very impactful moment);

(3) Classifying each reaction by reading the guide of reactions that was provided to them to identify a category. Students could also make their own categories if appropriate ones were not present in the guide;

(4) Colour-coding reactions by themes and categories found in the guide and writing these on sticky notes; and

(5) Digitizing and organizing their map with the Inspiration software.

This methodology, facilitated by Amélie, allowed students to document their process in real time, and also come back to it over the course of the term. The students could then confirm and inform their choices and their gestaltic impressions of experiencing making, all the while accounting for their processes.

Coding a Storytelling Project with Scratch: From Musical Melodies to Multimodal Narratives

Jenny, a Chinese teacher with a BFA in musicology, partnered with Grace, a Jordanian music and literature educator. Amélie's one-on-one interviews and ethnographic field notes indicated that Jenny and Grace wanted to combine literacy studies with music education for their project, in line with the readings they had done on multimodality. They decided to adapt a scene from a short story on international law and human rights into a brief coded animation using Scratch. The narrative presented a bystander that becomes involved in a bullying situation affecting another's life. The activity around the animation consists of the teacher reading the story to the class while intermittently stopping at narrative decision points for students to insert appropriate background or digitally-created music through body movements and related situations. The exercise recognizes the value of collaboration, as students work together to select or create music, and emphasizes students' abilities to troubleshoot, restart, make, and create their own projects and artifacts. In the section that follows, we give background information about Jenny and Grace, how their project came to fruition, their MakerMap documentation processes, and analysis from the MakerMap and reflective discussion findings. Implications for teacher education appear in the discussion section, and we conclude with the significance of this study for professional development and teacher practice.

Documenting Teachers' Affinities Between Storytelling, Coding, and Music

In her interview, Jenny noted how she decided to produce music from do-it-yourself (DIY) instruments to accompany the animation while Grace coded the movements within Scratch. In her MakerMap commentary, Jenny found early in the process that the DIY instrument sounded 'dry' and their imagined project was too 'vague'. Upon learning that Grace had also been creating digital music in Scratch for their animation, Jenny expressed in her interview how she was surprised to find their plans had altered, and noted a lack of communication in their partnership, felt frustrated about her inexperience with DIY instruments as well as Scratch, and considered abandoning the project altogether. However, she found reassurance and motivation in creating a storyboard (Jenny, interview) to help her understand and 'declutter' the creative process (Jenny, commentary). As expressed in her interview, Jenny produced several animation artifacts in succession, and after identifying Scratch's human characters as raising problematic issues of cultural appropriation, she decided to incorporate animal characters instead (Figure 1). Scratch-made narratives include premade characters and avatars that are difficult to 'fit' into predetermined storylines (e.g., Cinderella). As other studies have found, these constraints at times allow for posthuman play, whereby animated characters become the story, and students engage with them as a result, as opposed to the contrary (Lemieux & Rowsell, 2021; Rowsell et al., 2018). Grace noted this limitation in her MakerMap (Figure 2, under Additional moments II).

Figure 1

Storying Non-Humans in Scratch Narratives

Jenny revisited combined self-produced drum sounds with tunes from Scratch's library, noting in her MakerMap commentary how she "felt happy about every choice that [she] made during this process". Grace, in contrast, reflected on the broad significance of the process and its potential application across contexts. Her inspiration for the project was to bring together her interests in music teaching, literacy, and humanitarian international law (Grace, interview). She felt there was a strong connection between felt responses and how music could evoke that "some people need to have their feelings moved in a different way," as she said in her interview. Grace saw an affinity between music and coding in particular:

> The brain needs to understand the symbols. It's transcribing the symbols and thinking of it, and then applying what you comprehend and perform[ing] it by finger movements. And this is very similar to what you do in coding. You need to comprehend and then apply it and then there's a nice outcome that you'll be proud of. (Grace, interview)

Grace estimated in her interview that 60%-70% of teachers are "hesitant to use…technology in teaching," and that teachers ought to be encouraged to find a connection between coding and their subject area. Her assertions motivated us to explore some challenges teachers face, notably the difficulties associated with utilizing novel technologies for pedagogical purposes in classroom settings.

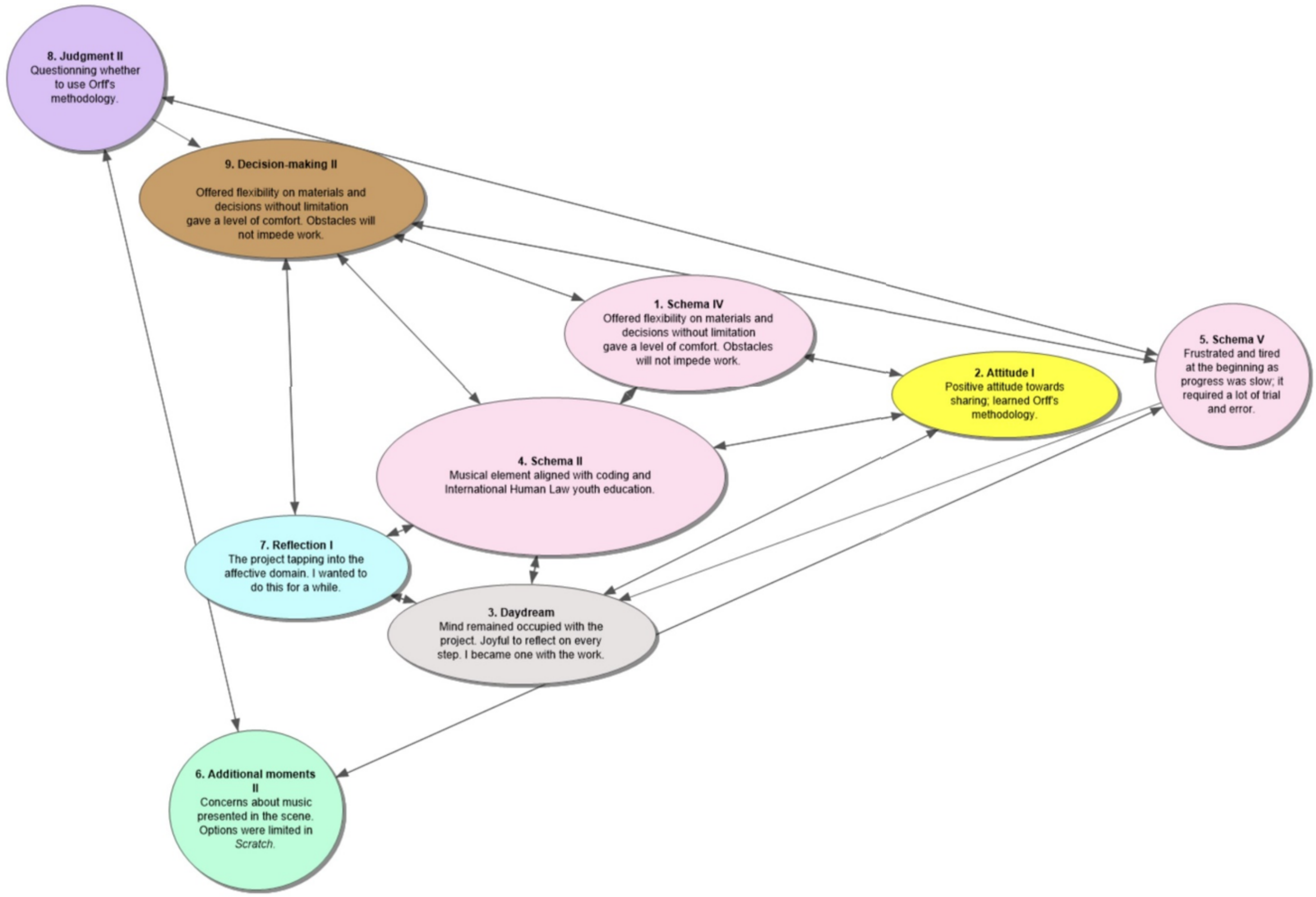
Documenting Maker Processes Through MakerMaps

The MakerMap aided Grace in understanding a process she identified as moving from knowledge to experience, to creativity, and finally to wisdom, leading to "self-improvement" and "self-awareness" as she shared in her interview. Grace's MakerMap (Figure 2) speaks to this awareness through the reactions she had while recording the music and coding the narrative. Numbers in the circles represent the order in which those thoughts were noted on paper. The arrows represent the relational thinking that took place between herself and moments of making. The colour-coded circles point to the different categories of reactions, with a strong emphasis on schematic expression (with different subcategories II, IV, and V). Schematic expression echoes, in the guide of reactions, associative thinking between the learner and previous knowledge or experiences, beliefs, values, and background. Grace's observations on 'becoming one with the [art]work' (Grace, MakerMap) points to our earlier observations around coding, where coding shapes the learner (as opposed to the constructivist narrative where the learner unidirectionally shapes the coding). The argument here further lies in the judgment and decision-making categories, in which Grace hesitates between using Orff's music instruction theory and following her intuitive tastes in music, as she wrote in her commentary. Mapping this hesitancy allowed her to clarify these relationships, bearing meaning-making across reactions, and seeing her coding composition as a sum of its parts over mind, body, and matter.

Jenny's MakerMap (Figure 3) is the one described at the beginning of this article, in which maker discourse can be seen in her captions describing the process: 'explore', 'combination', 'create', 'choices', and 'story'. These words invoke a sense of discovery associated with literacy practice, acknowledging how process affects learning. Jenny's surprise in learning that the music she was preparing for in a hands-on manner was also being created digitally by Grace emphasizes the need for an ongoing collaborative approach, as Jenny pointed at in her interview. This collaboration was frustrating at times, as Jenny noted in her MakerMap under the Emotions category. Jenny's nervousness about adapting a written story for movement, and her solution to use a storyboard to proceed through the animation, was met with a remark from Grace to "just do whatever you want, despite Grace's openness regarding new ideas" (Jenny, interview). More attention to ongoing communication, or check-in discussions, might have produced a less fraught atmosphere for project creation.

Figure 2

Grace's MakerMap

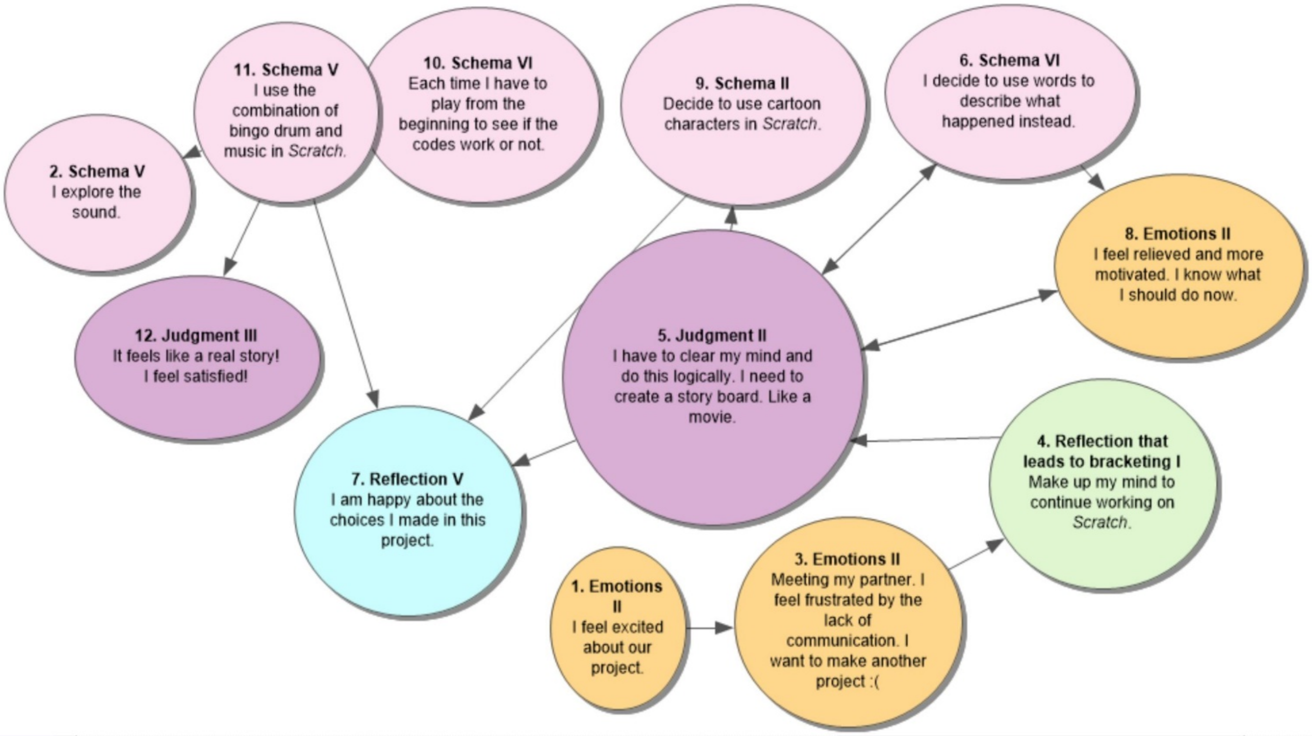


Jenny's MakerMap

Jenny's comment about Scratch's cultural appropriation of human characters relates to her observation that the human movements were not accurate, nor were they sensitive to lower socioeconomic classes, and we agree with her position. As she noted during her interview, there was a lack of diversity in characters. Her critical awareness demonstrates the need to engage with digital technologies critically and consider issues of racialized representation on widely used and accessible platforms, especially in education.

Figure 3

Jenny's MakerMap



Making Stories, Making Music, Making Progress: A Discussion on Documentation

One can speculate on whether this literacies exercise would have been as effective had Jenny and Grace not undergone any difficulties of collaboration, communication, and skills development in their role as learners, rather than as teachers. The various lessons to which Jenny and Grace were exposed during their encounters with coding highlighted the importance of documenting teachers' literacy processes to, in turn, offer more informed support to students who are themselves learning through making their way through coding. With the presented emphases—composition, coding, reactions, process, and teaching practice implications—new areas of literacies in the classroom are enriched, documenting processes is affirmed, and professional development in teacher education is nurtured.

In the coding projects, Jenny's Scratch-recorded music production was superseded by learning the platform's music resources and combinations; this met her goal to "boost the literacy learning" of students (Jenny, interview). As Grace noted in her interview, "coding is essential in every aspect of life", thanks to cellphones and computers, refuting the beliefs that coding is "complicated", "difficult", or "wastes time". The use of MakerMaps was particularly helpful for Grace, who indicated in her interview how she became "more aware of things that [she] thought about and applied in the project".

Together, Jenny and Grace achieved their goal of making a project incorporating music learning and coding practice to produce a multimodal text. The framework of sonics and collaboration, from the teacher reading the original short story to the class and the cooperation of students designing musical interludes for the animation, provide still more instances of new and refashioned intertextual instances of multimodality.

Grace holds teaching certifications in English literature, English as a Second Language, and music. Her experiences teaching in these areas make cross-interpretations of learning not only likely but enriching. Jenny has also taught music and English to students in China, and while she first thought to apply musical soundtracks to their project, she came to recognize that moments in their animation required different and corresponding sounds; for example, drumbeats to express running footsteps, and tension expressed with music in a minor key, "a little bit of shadow music, like [the] feeling" (Jenny, interview). This is the redesign and recreation of overlapping, multiple modes of meaning that produce digital and multimodal literacies. Further, and as important, is the need to document how these complexities emerge, as there is a need for data about teachers' metacognitive strategies occurring during their online learning activities to better understand how learning environments operate (Beach et al., 2020).

Why Attuning to Process Matters

Both Jenny and Grace noted affect-laden aspects of music that further strengthen their understanding of literacies. Jenny's comments about the music accompanying their animation were strongly felt. She refers to "slow-paced music," "vibe," "tension," "sadness," and "moving" sounds, as explained in her interview, to match the animation action. In parallel, the reactions that music evokes may enliven and dynamize relationalities:

> Sometimes there's feeling from your emotional feelings about music. But, if you dig really deep into music, there's math, there's everything in music. And, for example, the presentation about the beat in the music, it can help learners to know the punctuations in the readings. (Jenny, interview)

For her part, Grace saw music as activating her responses: "I'm one of the people that if there's no music, I kind of have no feelings. Like, if I want to really cry or be emotional, I'd want to listen to music" (Grace, interview). She felt that people do not generally think about sounds they are hearing, taking both positive and negative sounds for granted, but that doing so is an area open to investigation (Grace, interview). This could lead to insights into affect in relation to learning[2], which has emerged as a separate but related aspect of coding practice that develops socialization (Poth, 2019). Jenny and Grace drew on these skills just as their students would be expected to do, in terms of negotiating communications difficulties and task decision-making; in doing so, they were able to recognize and document their individual learning processes.

From Unfolding Uncertainties to Embracing Literacies Work Through Documentation

Jenny had some reservations about the class, unsure about what would be involved; however, as she read the course materials, which included an explanation of MakerMap design, and became more

[2] See Dernikos (2020) for posthuman considerations of the affects of sounds and silence in early childhood, as well as those of Jon Wargo and Cassie Brownell.

familiar with the class, she grew "clearer and clearer" about the ideas of MakerMaps for education (Jenny, interview). She also came to understand the ways in which making, in this case incorporating music learning into storytelling and animation, might support universal and affect-laden modes of learning: "music is universal. My instrument is a string instrument and some people say it's like people talking … I think the music embeds emotions and information" (Jenny, interview).

Grace felt that few adults were interested in learning coding and referred to herself as someone who was unable to "grasp [coding] that fast" (Grace, interview). She did identify her desire for learning as a strength, as well as her eagerness to apply her learning, as specified in her interview. This disposition is common to adult learners who frequently direct their learning towards implementation in their immediate circumstances (Knowles, 1980).

Jenny and Grace similarly reported increased self-awareness of their learning process through making. The MakerMap and associated commentary Jenny produced reflected her gradual understanding about the project, its stages, her enthusiasms and frustrations, and her pleasure at finding how storyboarding could reinvigorate her passion for the project. Grace entertained the possibility of emerging knowledges by slowing down and not rushing the making process: "One of my traits [is] I jump quickly into [work] … I want to go to the next step and next and next … the MakerMap make me step back and think and comprehend and enjoy every step" (Grace, interview). Attending to these processes allowed both teachers to engage more meaningfully in their compositions.

Implications for Teaching: Instances of Practice

Jenny commented on her future plans to introduce younger students to a well-known piece of music and allow them to compose their own lyrics to it, but she was aware that in her current institution the teaching of English was an academic endeavour with a very "specific curriculum" (Jenny, interview). She was cognizant that not every teaching situation is as receptive to incorporating composition activities. In her interview, Grace described "want[ing] to experiment with" applying humanitarian models from Red Cross training to her teaching, noting that the facilitators of that course emphasized its usefulness in "any subject matter" for junior high students, such as "social studies, with history, with music…". In the graduate course, Grace wanted to see the outcome of merging music, literacy, coding, and humanitarian international law; she was "really happy with that experience" (Grace, interview). Grace reacted positively and strongly to the class and its structure of experimentation, play, and knowledge production, calling the processes it examined "fun," "easy," and "simple" to navigate: "I think more of this kind of education needs to be there in the education system, whether in schools [or] universities" (Grace, interview). Teacher colleagues who are themselves metacognitive in their approach model a clarity of vision, rely on their judgment rather than prescribed routines, and implement professional development in classroom instruction (Duffy, 2008). Jenny and Grace independently recognized that integrating making principles into the curriculum or their adoption by institutional administrators is an ongoing challenge. After the course, while both felt capable themselves of making use of digital coding technologies in their classroom activities and resources, they identified how teacher colleagues might find it challenging to connect their subject areas with technology integration. While Jenny asserted in her interview that she would not necessarily incorporate the principles she used, Grace felt encouraging teachers to use "technology in their teaching in any subject matter" would rectify this gap (Grace, interview).

Significance of the Study

This work on literacies lays the ground for more research in teachers' professional development specializing in digital storytelling using coding. In this case study, Jenny and Grace produced a digital story for classroom use within a graduate literacy course and documented their processes through MakerMaps. Their insights generated considerations for teacher practice regarding not only coding integration for professional development, but also accounting for the eye-opening advantages of teachers' documentation processes.

Jenny and Grace's introduction to multimodal texts and digital programming were helpful in navigating situations that were new to them; at-times rocky collaborations, critical thinking tied to social issues, and interdisciplinarity contextualized these ventures. Their reactions to music in part from their musical knowledge enriched their project and awareness, laying the groundwork for them to negotiate different musical approaches common to making practice. Jenny's learning was shaped by a sensitivity to process work, while Grace's understanding proceeded from her committed technological interest and desire for implementation. Their MakerMaps were complex and, in Grace's case, opened the way for a discussion about personal improvement through lifelong learning. Both Jenny and Grace recognized in their interviews specific barriers to incorporating making practice into their teaching: for Jenny, the limitations of institutional support and, for Grace, the absence of support for teachers to acquire digital literacy skills. In terms of collaboration, both Jenny and Grace recognized the challenges of making together, all the while finding ways to listen to, and work with each other.

Conclusion

Research on literacies in this context recognizes two professional benefits relevant to Jenny and Grace's experiences. First, there are benefits for co-construction of knowledge in teachers' professional development. As such, contextual application of technologies "considers the application of technology in combination with pedagogy and content" (Cohen et al., 2018, p. 39), as both Jenny and Grace came to understand when combining their musical knowledges with other content and forms, so that teachers are invested in the process of finding meaningful and aligned processes and multimodal texts. Jenny and Grace, acting both as learners and teachers, carried out "digital participatory pedagogy" (Dooley et al., 2016, p. 53) in the connective work of preparing for students' additions to their animation. Their collaboration "stands in contrast to the ways that individual achievement is rewarded in schools" (Tucker-Raymond et al., 2016, p. 210) and offers growth in shared knowledge production.

Second, making practice regards documentation as integral, whether captures of processes are created through map-making, as was the case for Jenny and Grace, or through other means ranging from blog posts (Rodriguez et al., 2018) to videos (Peppler & Bender, 2013) and 3D-printed materials (Keune

& Peppler, 2019). The emphasis on tinkering encourages recording of attempted solutions or improvements through lists and diagrams, aligning with formal education imperatives to show one's work and embodying good professional development practice in sharing one's understandings with teacher colleagues.

This study showed that there is considerable potential for literacies to enrich teachers' professional development through such practices as documentation. Jenny and Grace used the MakerMap to account for their learning of literacy processes, inscribing their reactions in relatable ways to those they would ask of their students. Their learning is meaningfully reflected through their experiences of coding and documenting, both activities emphasizing attention to process. Offering teachers the opportunity to acquire coding skills, engage in tinkering, and reflect on processes makes for valuable contributions to teachers' professional development practice. Furthermore, it enhances the metacognitive capacities that result in more effective teaching through a strengthened awareness of one's own capacities and potential in literacies research. Through their own encounters with documenting multimodal texts that refashion representational forms, teachers like Jenny and Grace can drive instruction that raises awareness of classroom technologies, promotes teachers' technological confidence, and contributes to pedagogical discourse. Of importance, we argue, is deconstructing the notion that collaboration always goes smoothly, despite resulting in digital compositions. Deromanticizing collaboration speaks to the realities of relational work, and relational work can be both challenging and instructive. Documenting those relationalities can help teachers, and their students, realize that àliteracies present human realities that are central to learning in an era of collaborative and participative practices.

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Proposition d'une typologie des pratiques effectives de programmation visuelle

A Typology Proposition of Effective Visual Programming Practices

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Résumé

Cet article présente les résultats d'une étude de cas multiples menée auprès de 18 élèves du primaire au Québec, Canada. L'objectif de celle-ci était de proposer une typologie des pratiques effectives de programmation visuelle d'élèves du primaire. En plus d'offrir un portrait détaillé des pratiques mobilisées par les élèves dans le cadre de cette recherche, nous présentons une typologie des tâches de programmation visuelle pour des élèves du primaire en nous appuyant d'une part sur la littérature, et d'autre part sur les données empiriques de l'utilisation d'un scénario pédagogique qui permet aux élèves de mobiliser leurs habiletés en programmant un robot humanoïde appelé NAO. Cette proposition de typologie compréhensive et adaptée offre un potentiel pédagogique non négligeable, que ce soit quant à la conception de scénarios pédagogiques mobilisant la programmation visuelle à l'enseignement primaire, ou au développement de manuels ou guides pédagogiques destinés aux élèves ou aux enseignants du primaire.

Mots-clés : programmation ; typologie ; robotique ; primaire ; pratiques effectives

Abstract

This article presents the results of a multiple-case study conducted with 18 primary school students in Quebec, Canada. The objective of this study was to propose a typology of effective visual programming practices of primary school students. In addition to offering a detailed portrait of the practices mobilized by the students in this research, we present a typology of visual programming tasks for primary school students based on the literature and on empirical data from the use of a pedagogical scenario which allows students to mobilize their skills by programming a humanoid robot called NAO. This proposal for a comprehensive and adapted typology offers a significant pedagogical potential, whether for the design of pedagogical scenarios mobilizing visual programming in primary education, or for the development of textbooks or pedagogical guides for primary school students or teachers.

Keywords: programming; typology; robotics; primary school; effective practices

Contexte

Les compétences du 21e siècle sont considérées comme étant l'une des façons d'approcher l'omniprésence technologique (Forum économique mondial, 2015). Parmi ces compétences, on retrouve la collaboration, la résolution de problèmes, la créativité, la pensée critique et plusieurs autres (Chalkiadaki, 2018). En filigrane de ces nombreuses compétences, on retrouve la programmation (Romero, 2017). L'apprentissage de la programmation et la connaissance du fonctionnement des appareils technologiques offrent aux apprenants un bagage de connaissances pertinentes pour le marché du travail, qui a vu se déployer ce que plusieurs appellent déjà la quatrième Révolution industrielle, où la technologie (intelligence artificielle, robotique, etc.) est omniprésente (Lee et al., 2018). Le Forum économique mondial, dans un rapport prospectif, affirme que les individus qui auront du succès dans l'économie du futur seront ceux qui peuvent complémenter le travail des algorithmes, autrement dit, de travailler avec « les machines » (2018, p. 3). Cela étant dit, notre intérêt pour l'utilisation de la programmation à l'école va bien au-delà de l'impératif économique ou des préoccupations relatives au marché du travail.

Au Québec, trois documents officiels récents démontrent la volonté du gouvernement d'intégrer la programmation informatique dans le cursus scolaire. En effet, dès 2018, le Plan d'action numérique en éducation et en enseignement supérieur (Ministère de l'Éducation et de l'Enseignement supérieur, 2018) présentait le souhait d'« accroître l'usage pédagogique de la programmation informatique » (p. 27). En 2019, le Cadre de référence de la compétence numérique (Ministère de l'Éducation et de l'Enseignement supérieur, 2019), dernière politique en matière de numérique pour notre système d'éducation, y faisait aussi référence : « [D]évelopper sa pensée informatique, notamment par le développement de sa compréhension et de ses habiletés à l'égard de la programmation informatique » (p. 14). Enfin, plus récemment a été publié le guide *L'usage pédagogique de la programmation informatique*, dans lequel on souligne le grand potentiel de la programmation informatique, notamment pour « structurer sa pensée », c'est-à-dire pour développer son « raisonnement logique et l'esprit critique » (Ministère de l'Éducation, 2020, p. 7).

Plusieurs auteurs se sont intéressés à l'utilisation de différents dispositifs avec des élèves du primaire. Par exemple, certains ont documenté les représentations d'élèves de maternelle d'opérations élémentaires de programmation pour faire déplacer le robot BeeBot (Komis & Misirli, 2011), et d'autres ont étudié empiriquement le lien entre la pensée informatique d'élèves et la programmation (Noh & Lee, 2020). Plus récemment, des auteurs ont observé les habiletés associées à la pensée informatique lors d'activités de programmation en dyades au primaire (Wei et al., 2021).

Cet article présente l'un des objectifs spécifiques d'une recherche dont l'objectif général était de décrire et comprendre les effets de la programmation informatique sur la mobilisation de compétences de résolution de problèmes et de collaboration d'élèves du primaire. Nous avons choisi d'observer les pratiques effectives de programmation en tant que contexte dans lequel étaient mobilisées ces compétences. Outre la taxonomie des types de tâches de programmation proposée par Bower (2008), qui offre une perspective théorique et macroscopique peu adéquate pour l'enseignement primaire, il a été difficile de trouver des études proposant des classifications ou des catégorisations des pratiques associées à la programmation au primaire. L'objectif au cœur de cet article est donc la proposition, en s'appuyant sur la littérature, d'une typologie des pratiques effectives de programmation visuelle d'élèves du primaire lors d'activités où la collaboration était centrale. Bien que les analyses relatives à la résolution de problèmes et à la collaboration ne soient pas abordées dans cet article, les éléments conceptuels et théoriques associés à ces compétences permettent une compréhension du contexte d'observation des pratiques effectives de programmation.

Cadre de référence

L'approche socioconstructiviste offre des assises théoriques fort utiles à notre étude des pratiques effectives de programmation d'élèves du primaire. Elle met en lumière les dynamiques inhérentes à la collaboration et est à l'origine de certains de nos choix méthodologiques. Par exemple, Wood et al. (1976) avancent que, malgré les capacités naturelles de résolution de problèmes d'un enfant, il convient de tenir compte de l'apport d'autres pairs plus compétents pour l'assister dans le processus. D'ailleurs, cette disparité des compétences individuelles amène plusieurs points de vue différents pour la résolution d'un même problème, se traduisant à terme par un apprentissage par la voie de l'autre (ou des autres). Notons ici que l'intérêt principal de cette confrontation des idées est l'effet sur l'apprentissage, puisque selon Vygotsky, « l'enfant peut toujours faire plus et résoudre des problèmes plus difficiles que lorsqu'il agit tout seul » (1997, p.182).

La programmation, fortement associée au processus de résolution de problèmes, est définie comme étant l'action d'écrire, à l'aide d'un langage informatique, une série d'actions qui sont interprétées puis exécutées par un ordinateur (Blackwell, 2002). Le programme permet donc de médiatiser les interactions entre l'humain et l'ordinateur. Considérant la nature de l'agent de traitement de l'information (l'ordinateur), il est essentiel que les informations transmises soient dépourvues de toute équivoque ou ambiguïté (Turski, 1978). La programmation est une activité des plus propices à la mobilisation, voire au développement, de nombreuses compétences et processus cognitifs comme la résolution de problèmes (Lai & Yang, 2011) et la collaboration (Nugent et al., 2009). Avec l'avènement d'une multitude d'applications et de sites internet voués à l'apprentissage ludique de la programmation (p. ex. : Scratch, Code.org, Swift Playgrounds), nous pouvons sans doute parler d'une démocratisation de cette activité, à travers les âges. La programmation visuelle est l'une des adaptations pédagogiques de la programmation : elle permet de représenter les lignes de codes par des boîtes unies à l'aide de liens (Green & Petre, 1996).

Les pratiques de programmation dans la littérature

Les travaux de Ruf et al. (2015) offrent des pistes intéressantes propices à une transposition dans le contexte de l'enseignement primaire. En effet, ils ont recensé puis analysé des manuels ou cours d'apprentissage de la programmation pour l'enseignement secondaire et universitaire. Les tâches identifiées étaient destinées à des programmeurs novices, ce qui facilite l'adaptation pour des élèves plus jeunes. Parmi les 1 098 « tâches » recensées, les auteurs ont été en mesure d'établir 11 types différents. Il s'avère que par sa constitution, et le fait qu'elle résulte de l'analyse d'ouvrages pédagogiques destinés à des programmeurs novices, cette classification de Ruff et ses collègues est très pertinente à la réalisation de nos travaux avec des élèves au primaire.

Méthodologie

Dans cette étude de cas multiples (Karsenti & Demers, 2018; Stake, 1995), nous avons observé les pratiques effectives de programmation visuelle d'élèves du primaire. Pour ce faire, nous avons constitué un échantillon par contraste-approfondissement (Pires, 1997), nous permettant d'aller plus en profondeur dans l'explication du phénomène observé par la juxtaposition des cas. Cet échantillon intentionnel (Fortin & Gagnon, 2016) est composé de six groupes-classes de trois écoles du Québec, chaque cas étant associé à un groupe-classe (Tableau 1). Ce dernier s'avère être un groupe naturel existant à l'extérieur du contexte de la recherche (LeCompte & Preissle, 1993). Aucun critère d'exclusion n'a été appliqué au sein des groupes. Nous avons néanmoins accordé une importance au caractère diversifié des différents groupes composant l'échantillon, tant au niveau du statut socioéconomique, du milieu – rural ou urbain – et du type d'école, qu'elle soit alternative ou traditionnelle, privée ou publique. Cela répond au critère de diversification externe des échantillons par cas multiples (Pires, 1997).

L'école A, située à Montréal, est une école alternative[1] accueillant des élèves du primaire et du secondaire. Les groupes n'étant pas formés en fonction de l'âge[2], les participants du groupe A1 (n = 13) sont de différents niveaux scolaires, bien que les élèves du primaire (3^{e} cycle) soient plus fortement représentés. L'école B, aussi située à Montréal, a un indice du seuil de faible revenu de même qu'un indice de milieu socioéconomique au 10^{e} rang décile, les niveaux maximums pour ces deux indices de dé favorisation du ministère de l'Éducation et de l'Enseignement supérieur du Québec (2020). Les participants de cette école, c'est-à-dire le groupe B4 (n = 3), doivent faire face à différents défis inhérents au contexte socioéconomique. Ils sont au troisième cycle du primaire, c'est-à-dire en 6^{e} année. Enfin, l'école C se situe dans la grande région de Québec, en milieu rural[3]. Les élèves du groupe C1 (n = 2) sont en 5^{e} année et sont dans un groupe-classe réduit puisque plusieurs enfants rencontrent des difficultés d'apprentissage variées.

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[1] Selon le Réseau des écoles publiques alternatives du Québec, « l'école alternative est un milieu éducatif dynamique, prônant une approche participative, communautaire et humaniste dans laquelle chaque intervenant (équipe de direction, enseignants, parents) joue un rôle actif dans l'épanouissement de l'élève » (RÉPAQ, 2020).

[2] Les groupes ont été formés par le personnel enseignant.

[3] Selon les données de l'Institut national de santé publique du Québec (https://inspq.qc.ca/santescope/milieux-ruraux-urbains).

Tableau 1

Participants à l'étude

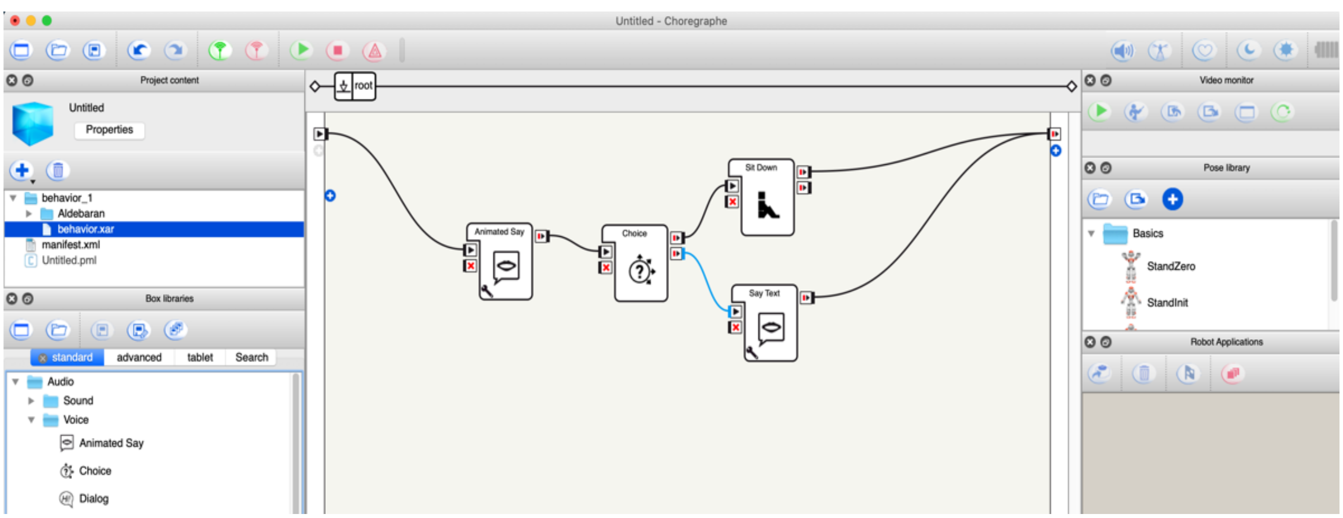
École	Groupe	Année	Milieu[4]	Filles (n)	Garçons (n)	Élèves (n total)
École A	A1	Multi	Urbain	9	4	13
École B	B4	6e année	Urbain	3		3
École C	C1	5e année	Rural		2	2
				12	6	18

Collecte de données

Nous avons implémenté un scénario pédagogique intitulé Deviens un maître NAO (Karsenti et al., 2019a), qui présente une série de tâches (réparties en 20 niveaux) visant à animer le robot NAO à l'aide de la programmation (Annexe 1). Numérotés de 1 à 20, ces niveaux induisent une progression permettant à l'élève de se familiariser avec le fonctionnement du robot et de réaliser des opérations de programmation de plus en plus complexes et variées. La programmation du robot NAO s'effectue avec le logiciel Chorégraphe (Aldebaran Robotics, 2014), dont l'interface est en anglais. Les pictogrammes et le guide d'accompagnement offert (Karsenti et al., 2019b) ont atténué significativement la barrière linguistique pour les élèves francophones. Ce logiciel repose sur le principe de programmation visuelle, c'est-à-dire que la principale façon d'animer le robot est de glisser des boîtes d'actions dans l'espace de travail, puis de les associer à l'aide de liens pour créer une séquence.

Figure 1

Interface de programmation visuelle du logiciel Choregraphe



La bibliothèque de boîtes (*box library*) du logiciel propose différentes fonctions qui permettent d'activer les fonctions du robot, allant des capteurs tactiles à la synthèse vocale, en passant par la reconnaissance

[4] Voir la note 3.

visuelle et le mouvement de ses bras, de ses jambes ainsi que de sa tête.

Les participants ont été placés en équipes de deux à cinq élèves pour réaliser les tâches du scénario pédagogique. Cette décision est motivée par le potentiel socioconstructiviste d'activités de cocréation à l'aide de la programmation (Romero et al., 2017) et, par extension, par la possibilité que les élèves puissent réinvestir seuls les apprentissages qu'ils auront réalisés en équipe (Vygotsky, 1934). Le nombre d'élèves dans chaque équipe variait selon le contexte du groupe. Chaque groupe se voyait remettre une valise contenant un robot NAO, un ordinateur portable doté du logiciel Chorégraphe, plusieurs copies imprimées des tâches du scénario pédagogique Deviens un maître NAO ainsi qu'un guide d'accompagnement en version électronique (Karsenti et al., 2019b), sur une tablette.

Afin d'observer les opérations de programmation accomplies par les équipes, nous avons utilisé deux instruments, le premier étant l'enregistrement des écrans des ordinateurs utilisés par les élèves, et le second étant l'observation vidéographiée. Des caméras ont été installées devant chaque équipe afin d'offrir une vue générale des actions à l'extérieur de l'interface Chorégraphe. Comme il s'agit de programmation impliquant l'animation d'un robot, ce second instrument s'avère utile pour compléter les données des enregistrements d'écran.

Traitement et analyse des données

L'analyse systématique des données a été effectuée sur les enregistrements d'écran afin d'observer les pratiques effectives de programmation dans l'interface du logiciel Chorégraphe. Il est à noter que les données analysées en lien avec le sous-objectif présenté dans cet article représentent une portion du corpus total. Ainsi, dans le but de proposer une typologie des pratiques effectives de programmation visuelle d'élèves du primaire, nous avons analysé les séances d'une équipe par école, et ce, pour trois visites, soit un total de neuf séances. Cela nous a permis d'analyser des données diversifiées tout en obtenant un portait complet, puisque toutes les équipes réalisaient les mêmes tâches présentées dans le scénario pédagogique commun. L'analyse des données a été réalisée avec le logiciel NVivo 12 (QSR International, 2020), où les catégories – et les codes associés – (Paillé & Mucchielli, 2005) ont été obtenus de façon inductive, tout en s'appuyant sur la classification proposée par Ruf et al. (2015) et au niveau du scénario pédagogique Deviens un maître NAO.

Résultats

En procédant, en amont, à l'analyse des notes de terrain, puis à l'analyse du corpus de données, nous proposons la typologie suivante (Tableau 2), inspirée de travaux de Ruf et ses collègues.

Le principal changement est lié au terme « écrire », qui n'est pas cohérent avec la programmation visuelle. Nous avons donc opté pour le terme « assembler », que nous avons subdivisé en opérations secondaires : chercher les boîtes, sélectionner les boîtes, lier les boîtes entre elles et enfin paramétrer ces boîtes. Certaines des pratiques de la classification de Ruf et ses collègues n'ont pu être observées : nous aborderons cela dans la discussion.

Tableau 2

Typologie inspirée de Ruf et al. (2015)

Pratiques de programmation
Assembler (opérations fondamentales) - Chercher - Sélectionner - Lier - Paramétrer
Assembler à partir d'une sélection préétablie
Ajuster, étendre ou compléter
Optimiser
Déboguer
Tester

Analyse des pratiques de programmation visuelle observées

Nous présentons ici chacune des pratiques de programmation observées en offrant des exemples concrets tirés du corpus de données.

Assembler

L'assemblage représente une agglomération des pratiques que nous qualifions de fondamentales pour la programmation visuelle. Leur caractère fondamental se manifeste par leur nécessité et leur utilisation, ce qui fut le cas dans notre corpus de données où trois pratiques observées sur quatre (76 %) relevaient de l'assemblage. Ainsi, la pratique d'assemblage devient en quelque sorte une métapratique incluant la recherche, la sélection, la liaison et le paramétrage. Le fait de décliner l'assemblage en différentes pratiques permet d'obtenir un portrait beaucoup plus précis de l'activité de programmation.

Assembler - Chercher

Contrairement à la programmation traditionnelle (écrite), la programmation visuelle nécessite une recherche afin de repérer la boîte, c'est-à-dire le code ou la fonction, qui sera utilisée dans le programme. Le logiciel Chorégraphe offre une bibliothèque de boîtes parmi lesquelles il est possible de chercher soit en naviguant dans l'arborescence de plusieurs dossiers thématiques, soit en utilisant un moteur de recherche. Ainsi, la pratique de programmation Chercher le code correspond au moment pendant lequel l'élève consulte la bibliothèque.

Assembler - Sélectionner

Une fois la boîte repérée dans la bibliothèque, l'utilisateur doit sélectionner la boîte avec le curseur et la déplacer dans l'espace de travail. Il est également possible de créer des boîtes à partir de formats préétablis, ne laissant à l'élève que la tâche de la paramétrer. Par ailleurs, certaines fonctionnalités du robot exigent l'activation d'un bouton. C'est notamment le cas du mode Animation, qui est utilisé afin d'animer les différents membres du robot NAO à l'aide d'une technique reposant sur le principe d'animation en volume (*stop motion*). La pratique Sélectionner le code représente donc les instances où l'élève a déplacé une boîte provenant de la bibliothèque dans l'espace de travail, a créé une nouvelle boîte dans l'espace de travail, ou encore a activé différentes fonctionnalités, comme le mode Animation.

Assembler - Lier

Cette pratique est propre à la programmation visuelle. L'utilisation de boîtes de code distinctes induit *ipso facto* la nécessité de lier ces boîtes d'une façon ou d'une autre. Dans notre cas, le logiciel permet de lier les boîtes entre elles à l'aide d'un fil noir, un système comparable à un réseau électrique, où l'impulsion du départ, c'est-à-dire au lancement du programme, parcourt un fil avant de traverser (activer) chacune des boîtes. Cet influx est d'ailleurs rendu visible par un point vert parcourant les fils dans l'interface de programmation du logiciel, ce qui permet à l'utilisateur de suivre la progression du programme en temps réel. La pratique de liaison renvoie donc à l'action d'associer les boîtes entre elles, de même qu'avec les points de départ et de fin du programme. Il est à noter ici que certains élèves éprouvaient parfois des difficultés à tracer ces liens, notamment associées à la motricité fine.

Assembler - Paramétrer

Le paramétrage fait référence à toute action impliquant d'entrer dans une boîte pour ajouter, modifier ou supprimer du contenu. Par exemple, lorsqu'il était question de faire parler NAO, les élèves utilisaient la boîte *Say* ou *Animated Say*, dont le paramétrage consiste notamment à écrire le texte que le robot devra réciter. Il est également possible de paramétrer la vitesse et la tonalité de la voix du dispositif. Un autre exemple de paramétrage est la création de boîtes *Timeline*, qui sont utilisées avec le mode Animation. Comme il s'agit d'animation de volume (*stop motion*), il est nécessaire de bouger le robot dans une position, d'enregistrer cette position, puis de le mettre dans une autre position, l'enregistrer, et ainsi de suite. L'enregistrement des positions sur une ligne du temps représente aussi une action de paramétrage. La pratique de paramétrage consiste donc à insérer des valeurs numériques ou alphabétiques, à ajouter ou déplacer des indicateurs sur des échelles ou à modifier des valeurs à l'aide de boutons.

Assembler à partir d'une sélection préétablie

L'assemblage à partir d'une sélection préétablie a été distingué des opérations fondamentales d'assemblage en raison de son caractère particulier. La particularité réside dans le fait que cette pratique ne peut être réalisée que dans un contexte où une certaine forme d'encadrement est offerte, et non en pratique autonome. En effet, cette pratique implique que l'usager se soit vu offrir une sélection de boîtes et que ce dernier choisisse l'une d'elles pour composer son programme. Par exemple, dans le scénario pédagogique que nous avons proposé, au niveau 11, les élèves sont appelés à réaliser une tâche pour laquelle quatre codes sont suggérés : « Voici certaines des boîtes à utiliser » (Karsenti et al., 2019a). Ces boîtes sont proposées à l'extérieur de l'espace de travail, ce qui implique que l'élève doit mobiliser les pratiques fondamentales d'assemblage afin d'utiliser ces boîtes suggérées (sélection préétablies).

Ajuster, étendre ou compléter

Similaire à l'assemblage à partir d'une sélection préétablie, cette pratique consiste à utiliser un code déjà présent dans l'espace de travail. La distinction est donc la présence des boîtes dans l'espace de travail, ce qui n'était pas le cas pour la pratique précédente. Dans notre corpus de données, nous avons été en mesure d'observer cette pratique au sein d'un même niveau, puisque chaque niveau de 1 à 9 est séparé en trois tâches. Ainsi, considérant la progression d'une tâche à l'autre, il est possible pour l'élève d'ajouter des boîtes ou de paramétrer à nouveau des boîtes utilisées antérieurement. Ces pratiques impliquent donc la modification d'un code déjà présent : il peut avoir été généré automatiquement dans l'interface, ou alors avoir été assemblé par l'élève précédemment.

Tester

Cette pratique concerne la vérification des programmes réalisés en les lançant, puis en observant le résultat de l'implémentation. Ce résultat peut prendre plusieurs formes selon le type de programmation. Dans le cas de la programmation d'un dispositif robotique, la vérification peut s'effectuer soit en analysant le déroulement du programme dans l'interface du logiciel, soit en observant le comportement du robot. Cette pratique permet donc de prouver le bon fonctionnement du programme conçu. Les données de notre corpus démontrent que les élèves ont parfois lancé le programme simplement pour voir le robot s'animer à nouveau, ayant préalablement confirmé, lors du premier test, que le programme fonctionnait adéquatement. Il est donc important de ne pas se limiter à la fréquence de cette pratique lors de l'interprétation des résultats de la grille.

Déboguer

Subséquente à la pratique de vérification (tester), la pratique de débogage survient lorsqu'il y a discordance entre le résultat obtenu et le résultat attendu. Le débogage s'impose alors comme un processus dont le but est d'identifier l'erreur (le bogue) et se conclut par une vérification réussie. Cette pratique est en fait une transposition du processus de résolution de problèmes, mobilisant ainsi plusieurs autres pratiques en vue de résoudre la situation. Le débogage est donc une pratique d'ordre général que l'on pourrait aussi qualifier de métapratique, comme l'assemblage. Or, ici les pratiques sous-jacentes ne sont pas propres au débogage en soi, mais bien aux pratiques d'assemblage fondamentales et de vérification notamment. En procédant de façon itérative, les élèves cernent le problème, tentent de le régler en modifiant le programme, effectuent un test, et ce, de façon itérative jusqu'à ce que le problème (bogue) soit résolu.

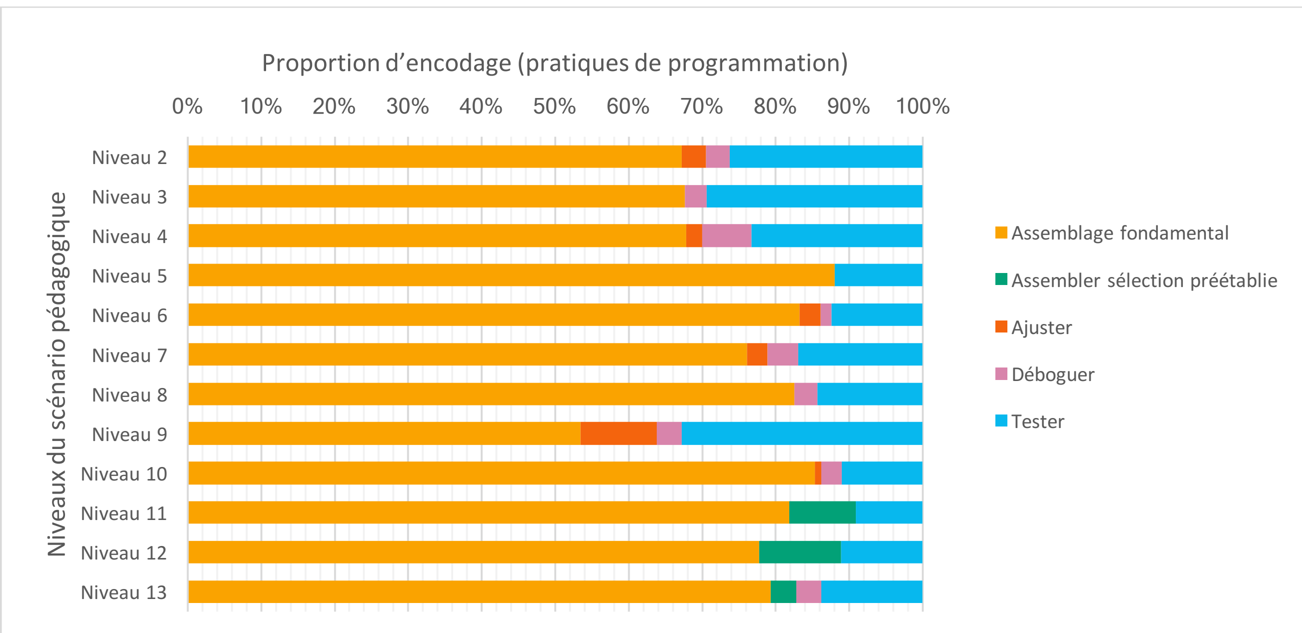
Mobilisation des pratiques de programmation visuelle

L'analyse des données a permis de démontrer dans quelles proportions les opérations de programmation ont été utilisées par les élèves (fréquence). La figure 2 présente donc les proportions d'encodage[5] des pratiques de programmation à chaque niveau du scénario pédagogique. Le niveau 1 n'a permis l'observation d'aucune pratique de programmation puisque ce niveau amène l'élève à interagir avec le robot à l'aide de ses capteurs tactiles et de la synthèse vocale : ces fonctions font partie de la vie autonome du robot, c'est-à-dire qu'elles sont actives sans programmation. Il est également à noter que le niveau maximal atteint par les participants est le niveau 13 en raison en raison du temps limité de collecte, ce qui explique l'absence d'encodage pour les niveaux 14 à 20.

On constate que l'assemblage fondamental représente une proportion importante des pratiques de programmation effectuées par les élèves lors des activités. En effet, bien qu'étant moins utilisé au niveau 9, il représente néanmoins une majorité des pratiques à chaque niveau (M = 75,8 %). La figure 3 illustre la proportion attribuée à chaque pratique d'assemblage fondamentale (fréquence), par niveau.

Figure 2

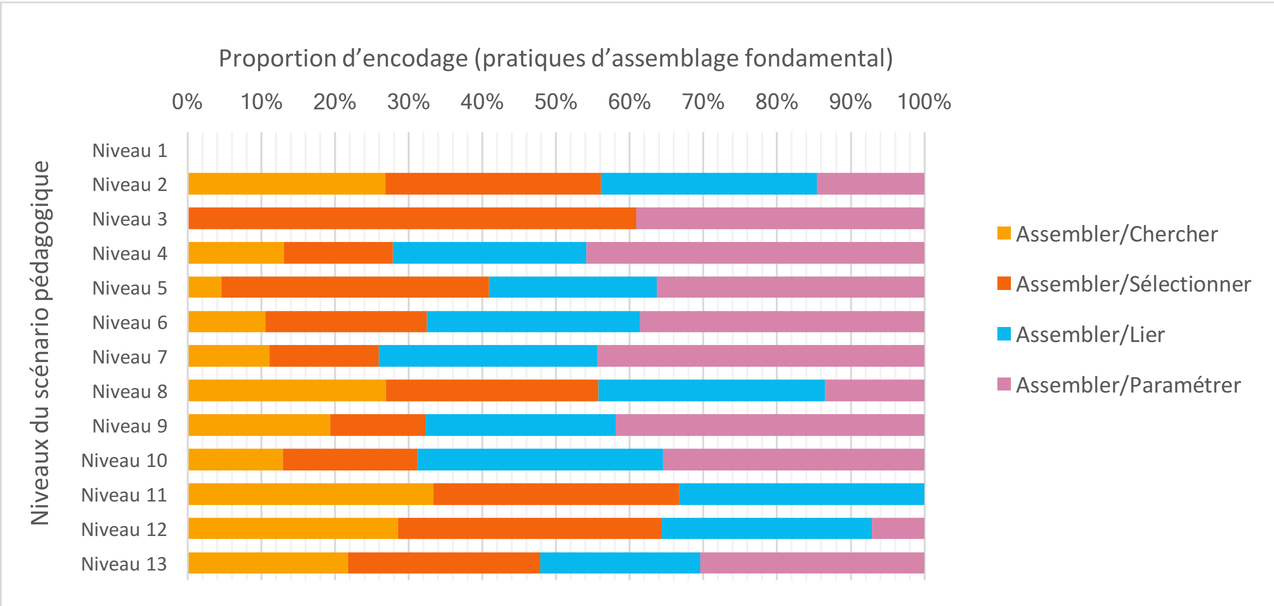
Pratiques de programmation par niveau du scénario pédagogique



[5] Le verbe *encoder* réfère à l'action d'attribuer un code à un segment du corpus de données vidéos (van der Maren, 2004). Nous utilisons le terme *encodage*, dans son emploi nominal, pour désigner l'ensemble de codes attribués.

Figure 3

Pratiques d'assemblage fondamentales (4) par niveau



Outre les proportions associées à la fréquence des opérations de programmation, nous avons cherché à savoir si le temps accordé à chaque opération était similaire. Le tableau 3 indique : (a) le nombre de minutes passées par les élèves à effectuer chacune des pratiques de programmation observées ; puis (b) compare les proportions de durée et de fréquence.

Tableau 3

Comparaison des proportions de durée et de fréquence d'encodage

Pratiques de programmation	Durée d'encodage (minutes)	Proportion (durée)	Fréquence	Proportion (fréquence)
Assembler (opérations fondamentales)				
Chercher	33	6,5 %	82	11,6 %
Sélectionner	13	2,6 %	126	17,8 %
Lier	28	5,5 %	149	21,1 %
Paramétrer	215	42,5 %	180	25,5 %
Assembler à partir d'une sélection préétablie	5	1,0 %	4	0,6 %
Ajuster, étendre ou compléter	25	4,9 %	17	2,4 %
Déboguer	119	23,5 %	22	3,1 %
Tester	68	13,4 %	126	17,8 %
	506	100,0 %	706	100,0 %

Les données obtenues indiquent une disparité entre la fréquence de certaines pratiques et leur durée. Cette disparité souligne une proportion considérablement plus importante tantôt pour la durée, tantôt pour la fréquence. Parmi les pratiques dont la fréquence surpasse la durée, on retrouve notamment la sélection, dont la proportion de fréquence est 6,8 fois plus élevée, et la liaison, dont la proportion de fréquence est 3,8 fois plus élevée. Inversement, la proportion de temps accordé au débogage est 7,6 fois plus élevée que la proportion de fréquence de cette pratique, ce qui signifie qu'elle est moins fréquente, mais qu'elle dure longtemps.

Discussion

Les données font état d'un phénomène intéressant : alors que certaines pratiques sont très fréquentes et de courte durée, d'autres sont peu fréquentes et de très longue durée. Lorsque l'on s'intéresse à la fréquence, on remarque que les pratiques d'assemblage fondamentales dominent à ce chapitre, suivies de la pratique de vérification (tester). Lorsqu'il est question de la durée des pratiques, c'est le paramétrage et le débogage qui se démarquent. Comme le paramétrage représente une partie cruciale du processus de programmation, il semble logique de constater qu'il occupe 42,5 % du temps observé pour l'ensemble des pratiques. Cette pratique recèle une importante partie de la complexité inhérente à l'activité de programmation puisqu'elle suscite la manipulation de variables et de données qui déterminent la logique interne de chaque code. Le paramétrage est d'ailleurs une pratique souvent utilisée dans le processus de débogage. Cela dit, pour le débogage, c'est le rapport entre la durée et la fréquence qui est digne de mention : la proportion de durée est 7,6 fois plus élevée que la proportion de fréquence. Ainsi, le processus de débogage peut s'avérer chronophage.

Les figures 2 et 3 démontrent que la mobilisation des pratiques de programmation dans chaque niveau du scénario pédagogique Deviens un maître NAO est similaire. Bien que des différences subsistent, expliquées notamment par la nature plurielle des défis proposés aux élèves, il demeure que les apprenants ont été en mesure de mettre en œuvre les pratiques de façon régulière au fil de leur progression dans les niveaux du scénario.

Typologie des pratiques de programmation

Cette étude empirique a mené, dans un processus itératif, à la déclinaison d'un ensemble de pratiques effectives de programmation d'élèves du primaire. Le tableau 4 présente la typologie à l'aide de descripteurs.

Tableau 4

Typologie des pratiques effectives de programmation observées

Pratiques de programmation	Descripteur
1. Assembler (fondamental)	
1.1 Chercher	L'élève cherche dans l'interface de programmation, à l'aide d'une bibliothèque ou d'un moteur de recherche, un code donné. Dans le cas des bibliothèques, il peut s'agir d'une liste du nom des codes, ou encore des boîtes elles-mêmes.
1.2 Sélectionner	À partir de la bibliothèque ou de tout autre emplacement dans

Pratiques de programmation	Descripteur
	l’interface, l’élève sélectionne ou génère une boîte, puis la déplace dans l’espace de travail, le cas échéant.
1.3 Lier	L’élève associe les codes (boîtes) entre eux et, s’il y a lieu, aux points de départ et de fin du programme. Cette pratique pourrait être sous-utilisée, voire inutilisée, dans le cas d’interfaces où le lien entre les boîtes est effectué par la juxtaposition de ces dernières (à la manière d’aimants). La pratique Sélectionner possède alors une double finalité qui inclut la liaison.
1.4 Paramétrer	L’élève ajoute des valeurs ou modifie et retire des valeurs préexistantes (par défaut). Ce paramétrage peut être effectué tant en surface, lorsque le paramétrage apparaît sur la boîte, qu’en entrant dans une boîte.
2. Assembler à partir d’une sélection préétablie	L’élève conçoit un programme incluant un ou plusieurs codes suggérés par un agent réel ou virtuel.
3. Ajuster, étendre ou compléter	L’élève utilise un ou plusieurs codes liés, déjà présents dans l’espace de travail, afin de créer un programme. Contrairement à l’assemblage à partir d’une sélection préétablie, où le code était suggéré, la pratique d’ajustement s’effectue sur des éléments déjà présents dans l’espace de travail (qu’ils y aient été placés par un agent réel, virtuel ou par l’élève lui-même, pour une autre tâche antérieure).
4. Tester	L’élève lance le programme et en vérifie le résultat. Cette pratique peut amener à améliorer (optimiser), déboguer le programme. La vérification peut aussi servir d’étape intermédiaire dans le processus de programmation, c’est-à-dire pour valider un code ou une portion de programme.
5. Déboguer	Après avoir constaté que le programme n’a pas donné le résultat escompté, l’élève part à la recherche du problème (bogue) dans l’implémentation du programme. Il s’agit d’un processus itératif dans lequel sont utilisées de nombreuses autres pratiques ; surtout la vérification (tester) et les pratiques d’assemblage fondamentales.

Pertinence de la typologie proposée

Cette proposition de typologie apporte un regard nouveau sur l’utilisation de la programmation au primaire. Considérant la démocratisation de l’usage pédagogique de la programmation informatique, il semble nécessaire d’offrir plusieurs balises afin d’encadrer cette activité à l’école. Le risque de limiter le potentiel de la programmation à son aspect ludique et motivant est bien réel. Ainsi, il est souhaitable que soient développés des scénarios pédagogiques ou des activités, comme celles de Romero et

Vallerand (2016), mobilisant la programmation de façon réfléchie, sans toutefois prétendre à l'exhaustivité de toutes ses facettes. Cette typologie offre à la fois des repères théoriques et empiriques pour la conception ou l'adaptation d'activités visant à mobiliser et à développer les compétences d'élèves du primaire par la programmation.

Limites

L'une des principales limites de notre recherche est le fait de n'avoir pu observer empiriquement que cinq types de programmation, et ce, en raison du scénario pédagogique que nous avons utilisé. Il y aurait certainement avantage à reproduire cette étude dans un contexte authentique de programmation où le scénario pédagogique permettrait d'observer d'autres pratiques.

Conclusion

L'objectif de cette étude de cas multiples était de proposer une typologie compréhensive et adaptée des pratiques effectives de programmation d'élèves du primaire. Après avoir décliné l'ensemble des pratiques observées auprès des apprenants de notre échantillon, il est devenu évident que les typologies et taxonomies tirées de la littérature n'étaient pas applicables au primaire. Cela a d'ailleurs confirmé la pertinence de notre proposition de typologie. Ainsi, les données empiriques nous ont permis de définir cinq types de pratiques. D'un point de vue scientifique, cet article pose les fondations d'un travail d'élaboration d'une typologie complète des pratiques effectives de programmation allant au-delà des limites inhérentes à un scénario pédagogique donné. Une telle typologie issue d'observations empiriques pourrait avoir des répercussions pratiques, par exemple en orientant la conception de matériel pédagogique de programmation. Notre travail ouvre également sur de nombreuses pistes d'approfondissements potentielles que nous souhaiterions explorer lors de recherches futures, notamment la validation de cette typologie auprès d'élèves du premier cycle du primaire, voire du préscolaire, ainsi que l'application de la typologie dans le cadre d'un autre scénario pédagogique.

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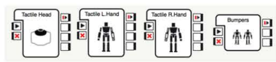
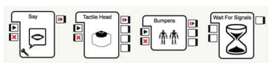
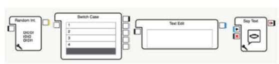
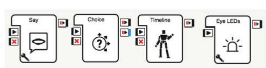
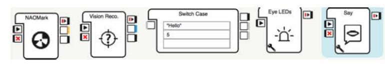
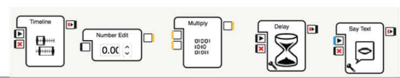
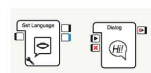
Annexe

Deviens un MAÎTRE NAO


Niveaux		Défis	Niveaux		Défis
1	◆	Vous devez doucement caresser le dessus de la tête de NAO pour qu'il réagisse.	6	◆	Vous devez faire poser la question suivante à NAO : « Aimes-tu les desserts ?» en utilisant la boîte *Choice*. Il doit vous comprendre et vous répondre « Moi, j'adore ça ! »
	◆◆	Vous devez dire « Salut » ou « Bonjour » à NAO jusqu'à ce qu'il vous comprenne et vous réponde. Demandez-lui, ensuite, « comment ça va ? ».		◆◆	Vous devez faire poser la question suivante à NAO : « Quelle est la capitale du Canada ?». Vous devrez proposer 3 choix de réponse, faire en sorte qu'il reconnaisse et félicite la bonne réponse ou demande de réessayer en cas de mauvaise réponse.
	◆◆◆	Vous devez demander à NAO de se coucher sur le dos ou sur le ventre.		◆◆◆	Vous devez faire poser la question suivante à NAO : « Quelle est la capitale des États-Unis ? ». Veillez à proposer 3 choix de réponse. NAO devra lever la main droite en cas de bonne réponse et lever la main gauche en cas de mauvaise réponse.
2	◆	Vous devez faire s'asseoir NAO en le programmant.	7 BRONZE	◆	Vous devez faire en sorte que NAO reconnaisse la balle rouge et la suive avec la tête.
	◆◆	Vous devez faire dire « Bonjour » à NAO en le programmant.		◆◆	Vous devez faire en sorte que NAO reconnaisse la balle rouge, se dirige vers elle, et s'arrête à 0,2 mètre d'elle.
	◆◆◆	Vous devez lui faire faire un *Bonjour animé* dans lequel il dira « Bonjour mon ami » en le programmant.		◆◆◆	Vous devez faire en sorte que NAO reconnaisse la balle rouge, se dirige vers elle en levant le bras droit, s'arrête à 0,4 mètre et dise la phrase : « Ma balle est ici, je la cherchais justement !».
3	◆	Utiliser la fenêtre *Robot View* pour ce niveau Vous devez faire tourner la tête de NAO à gauche.	8 ARGENT	◆	Vous devez faire apprendre à NAO deux visages.
	◆◆	Vous devez lui faire lever le bras droit.		◆◆	Vous devez faire en sorte que NAO reconnaisse votre visage et dise votre nom lorsque vous serez devant lui.
	◆◆◆	Vous devez lui faire bouger les deux bras en même temps.		◆◆◆	Vous devez faire en sorte que NAO reconnaisse deux visages et dise un message personnalisé différent en identifiant chaque personne.
4	◆	Vous devez faire avancer NAO d'un mètre en le programmant.	9 OR	◆	Utiliser le mode *animation* pour ce niveau Vous devez faire jouer une musique de votre choix à NAO.
	◆◆	Vous devez faire reculer NAO d'un mètre en le programmant.		◆◆	Vous devez faire jouer cette musique à NAO et lui faire faire une chorégraphie avec les bras (*boîte Timeline*).
	◆◆◆	Vous devez faire avancer NAO de 0,5 mètre vers la gauche et lui faire faire un «*Bonjour animé* » où il dit «Content de vous rencontrer !» en le programmant.		◆◆◆	Vous devez lui faire jouer la musique, puis lui faire faire une chorégraphie avec les bras, la tête et les jambes (boîte *Timeline*). Enregistrez la chorégraphie dans la librairie.
5	◆	Utiliser le mode *animation* pour ce niveau Vous devez faire lever le bras gauche de NAO, remplacer le nom de la boîte *Timeline* par « Bras gauche levé » et changer l'image en choisissant une proposée par le logiciel.	10 PLATINE		Utiliser le mode *animation* pour ce niveau Vous devez faire demander à NAO : « *Veux-tu que je te montre mon super parcours d'activité physique ?* ». A la réponse « oui », une musique commencera et NAO débutera sa série d'exercices que vous aurez programmé : ▪ NAO devra faire un trajet en forme de rectangle (1 mètre en avant, 0,3 m à droite, 1 m en arrière et 0,3 m à gauche) ; ▪ Il devra faire un exercice de votre choix au début, au milieu et à la fin du parcours en *mode animation*. Vous avez la possibilité de reprendre la chorégraphie du niveau 9 pour un des exercices. ▪ Quand il aura terminé il dira : « Ouf, ça fait du bien !» et s'assiéra sur le sol.
	◆◆	Vous devez faire lever les deux bras de NAO.			
	◆◆◆	Vous devez donner une nouvelle position à NAO sans qu'il ne tombe.			

Deviens un MAÎTRE NAO

Niveaux	Défis
11	Vous devez programmer des actions différentes en fonction des capteurs sensoriels qui sont touchés. Voici certaines des boîtes à utiliser :  Vous avez le choix : Demander à NAO de dire quelque chose, de danser, de bouger, de poser une question, etc.
12	Vous devez programmer NAO pour lui faire dire quelque chose uniquement après avoir appuyé sur deux de ses capteurs, et cela l'un après l'autre. Voici certaines des boîtes à utiliser pour réaliser ce programme : 
13	Vous devez faire un diagramme qui comporte 4 phrases que NAO devra dire au hasard. Voici certaines des boîtes à utiliser pour réaliser ce programme :  Ces 4 phrases doivent toutes être différentes et parler des robots.
14	Vous devez faire faire à NAO des mouvements (Boîtes *Timeline*) qui représentent des émotions (la tristesse, la peur, la joie, la colère et l'amour) et lui faire demander à quelqu'un de quelle émotion il s'agit. Il félicite la bonne réponse et enchaîne avec une nouvelle émotion à deviner jusqu'à ce que toutes les émotions soient correctement identifiées. Voici certaines des boîtes à utiliser pour réaliser ce programme : 
15	Vous devez construire une suite d'actions qui contient 10 boîtes différentes. Toutes les boîtes doivent avoir une utilité. **Attention**, il n'est pas possible de retrouver deux fois la même boîte.

Niveaux	Défis
16	Vous devez demander à NAO de reconnaître visuellement un ballon bleu, rouge ou vert. Il doit répondre correctement en parlant et en indiquant la couleur avec ses yeux. Vous pouvez lui apprendre les couleurs ou alors utiliser les NaoMarks. Voici certaines des boites dont vous pourriez avoir besoin : 
17	Vous devez faire dire à NAO « Bonjour jeunes humains, je suis content de vous voir après tout ce temps passé dans ma boîte », avec le mode *Python Script*. Voici certaines des boîtes à utiliser pour réaliser ce programme : 
18	À l'aide d'une boîte *Timeline*, vous devez faire s'agenouiller NAO sans qu'il ne tombe. Ensuite, vous demanderez à NAO d'énoncer un problème mathématique que vous aurez créé, qui demande de multiplier deux nombres entiers entre eux. NAO devra y répondre. Voici certaines des boîtes à utiliser pour réaliser ce programme : 
19	À l'aide d'une boîte *Dialog*, vous devez créer un programme qui permet à NAO de répondre à vos questions sur différentes capitales du monde. Voici certaines des boîtes à utiliser : 
	En utilisant les 3 types de boîtes *Dialog*, *Timeline et Python*, vous devez donner des consignes de vie de classe à NAO en anglais (Assoie-toi, lève-toi, écoute, va au tableau, lève la main, excuse-toi…). Il doit les exécuter.

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Sustainability and Scalability of Digital Tools for Learning: ABRACADABRA in Kenya

Durabilité et évolutivité des outils numériques d'apprentissage : ABRACADABRA au Kenya

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Abstract

This paper explores factors to increase the likelihood that the implementation of ABRACADABRA, a technology-based approach to teaching and learning literacy, endures and expands beyond the initial research. Started as a pilot study in 12 classrooms, the implementation spread to more than 500 primary classrooms over six years in five areas of Kenya. Drawing from research about scalability and sustainability of educational interventions and value-expectancy-cost theory, an exploratory survey was designed to interview a range of actors involved in the software implementation. We used a combination of an a priori and data-driven coding approaches to analyse the narratives. We then built a model exploring the relationship between expectancy-value-cost beliefs and the factors associated with implementation and sustainability. The model explained an important portion of variance in the self-reported intent to use the software with the most significant contributions from policies, professional development, and students. These findings may be useful in the context of low- and medium-income countries where no research-proven principles exist to building sustainable and scalable educational interventions.

Keywords: educational technology; sustainability factors; scaling; Sub-Saharan Africa

Résumé

Cet article explore les facteurs permettant d'augmenter la probabilité que la mise en œuvre d'ABRACADABRA, une approche technologique de l'enseignement et de l'apprentissage de

l'alphabétisation, perdure et s'étende au-delà de la recherche initiale. Commencée comme une étude pilote dans 12 classes, la mise en œuvre s'est étendue à plus de 500 classes primaires sur six ans dans cinq régions du Kenya. S'inspirant de la recherche sur l'évolutivité et la durabilité des interventions éducatives et de la théorie valeur-expectative-coût, une enquête exploratoire a été conçue pour interroger une série d'acteurs impliqués dans la mise en œuvre du logiciel. Nous avons utilisé une combinaison d'approches de codage a priori et axées sur les données pour analyser les récits. Nous avons ensuite construit un modèle explorant la relation entre les expectatives-valeur-coût et les facteurs associés à la mise en œuvre et à la durabilité. Le modèle explique une part importante de la variance dans l'intention autodéclarée d'utiliser le logiciel, les contributions les plus significatives provenant des politiques, du développement professionnel et des étudiants. Ces résultats peuvent être utiles dans le contexte des pays à revenu faible ou moyen où il n'existe pas de principes validés par la recherche pour construire des interventions éducatives durables et évolutives.
Mots-clés **:** technologie éducative ; facteurs de durabilité ; évolutivité ; Afrique sub-saharienne

Introduction

Education has been recognized worldwide as a key component of social systems that enables countries' sustainable development. To date significant progress has been made on bringing education to children. Yet, the global reference targets first set by the Millennium Goals (United Nations, 2000) and by the Sustainable Development Goals (UNESCO, 2015) are not being achieved as fast and effectively as intended. Recent UNESCO reports affirm that the "world is far off track" on attaining international commitments to ensure quality education for all youth (UIS 2019a; UNESCO, 2021a). By 2019, some 483 million children of primary and lower secondary school age lacked foundational reading skills after years spent in the schooling system (UIS, 2019b). The global pandemic has aggravated this learning crisis wiping out gains that the world made over a few decades through education efforts (UNESCO, 2021b). Research on educational practices has generated a rich knowledge base with the potential to improve teaching and learning and to optimize functioning of educational systems. However, for the research-based strategies to have real and widespread impact, they need to be viable in authentic environments of classrooms and schools and at scale. Hence, the UNESCO International Commission on the Futures of Education (2021a) calls for research and innovation to focus on detailing the conditions that lead to scaling effective practices. This paper explores factors that have potential to increase the likelihood that a technology-based approach to teaching and learning endures and expands beyond initial research.

Related Literature

Scaling and Sustainability of Educational Innovations in Developing Nations

Issues of scalability and sustainability in education are not new. The directions taken to study systemic educational improvement include Rogers' Diffusion of Innovation theory (1962), educational change (Fullan, 1982), curricular reform (Goodson et al., 1989), school change (Argyris, 1993), and education systems change (Christensen, 1997) to name a few. The first analysis of challenges involved in producing significant change in instructional quality at scale was prepared by Elmore in 1993. In international development, Myers' influential paper (1984) explained why going to scale is critical in order to have impact on educational policy and programming in countries with limited resources and capacities. Since then, scaling and sustainability of successful interventions have gained substantial traction in the global educational agenda.

However, the ever-growing body of systematic evidence on effective interventions in developing nations' educational contexts tells little about how to make an intervention work for many individuals and for a sustained time (Evans & Popova, 2016; Kim et al., 2020). For instance, the only randomized trial (Bold et al., 2018) focused on transferring a tested intervention on teacher hiring practices to national implementation. It found that the intervention produced higher student learning gains when implemented on a modest scale by a nongovernmental organization rather than the government. Also, Piper et al. (2018) reported a case about bringing a large government-supported pilot to national scale. Following a vertical scaling path, the reading program has been institutionalized through national planning mechanisms and involvement of national and international stakeholders (Piper et al., 2018).

Given a dearth of research on scaling educational innovations, the evidence generated outside education such as industry and agriculture has been tapped for the benefit of educational systems in developing nations (McLean & Gargani, 2019). However, suggesting that this knowledge is far from fully relevant to educational change, the Millions Learning report (Robinson et al., 2016) concluded that bringing to scale quality learning outcomes for children and youth continues to remain an abiding concern.

Further, scaling is only successful when sustainable; the relationship between the two has yet to be clearly articulated. For instance, research on educational change treats sustainability as a pre-condition for scale whether small or large. Coburn (2003) insists that the scale is meaningful over time only if the implementation can be sustained in the adopting schools. The institutionalization process including rules and regulations and implementation becomes the key in order for the innovation to be integrated permanently into the school structure and culture. Mioduser et al. (2004) underline the importance of the within-school spread. The big challenge in this process is to expand beyond the "islands of innovation" to "comprehensive innovation" that encompasses at least half of the teaching and learning in the school and most importantly affects its entire culture. After all, teachers are more likely to be able to sustain an intervention when it becomes the school's priority and the activities are aligned with it. This speaks to the existence of an interactive relationship between sustainability and adoption where innovations evolve over time through modifications based on teachers' needs and beliefs (Dede, 2006). In this process teachers reevaluate the degree and manner to which innovations are implemented, balancing implementation with perceived usefulness, costs, and expectations.

Value-Expectancy-Cost Framework

Based on Shepperd's (1993) motivational analysis of productivity losses in groups, Abrami et al. (2004) and Wozney et al. (2006) applied expectancy theory to construct a unified view of the diverse issues that influence a teacher's decision to implement an educational innovation and persist in its use. The Wozney et al.'s (2006) model posits that an educational innovation is more likely to be implemented if its perceived value and the likelihood of success are high, and if the benefits outweigh the costs of implementation. Specifically, a teacher's decision about whether to implement an innovation depends on how highly they value the strategy, how successful they expect it to be, and how important they perceive the costs of implementation to be. Value assesses the degree to which teachers perceive the innovation or its associated outcomes as worthwhile including benefits to the teacher (such as congruence with teaching philosophy, career advancement), and to the student (such as increased achievement, improved attitudes). Expectancy relates to teachers' perceptions of the contingency between their use of the strategy and the desired outcomes, and factors affecting these perceptions including internal attributions (such as teacher self-efficacy and skill), and external attributions (such as student characteristics, classroom environment and collegial support). Cost relates to the perceived physical and psychological demands of implementation and operates as a disincentive to innovating and may include class preparation time, effort, and specialized materials.

Influences on Sustainability and Scale

Multiple influences may affect the delicate balance of components constituting teacher motivation to maintain improvements they achieved by implementing an intervention. The literature suggests that factors that influence processes related to implementation and sustainability are attributes of the innovation, those of its users, as well as the features of the environment including those within and outside of the organization (Century et al., 2012).

Having reviewed the experiences of 14 educational programs in low- and middle-income nations, Robinson et al. (2016) implies that the program design, delivery mechanisms, finance, and an enabling environment are the factors of successful scaling. Evaluation research of information and communications technology (ICT)-based educational initiatives in developing countries groups these factors into individual and organizational, technological, economic, and political dimensions (Pouezevara et al., 2014). Individual and organizational dimensions relate to the individual practitioner and school capacity to sustain the intervention, as well as the organizational context encompassing leadership, school community including collegial culture and students, individual and collective capacity, ownership and expectations. Since the capacity of actors involved in implementation vary, careful attention to both training and support is required to meet the existing needs in technical, pedagogical, and content knowledge (Mishra & Kohler, 2006). Technological dimensions are concerned with the ICT needed to bring the educational intervention to teachers and students such as operation of infrastructure and equipment. Economic dimensions refer to costs and economic environment in which the innovation implementation unfolds. Political dimensions pertain to support for the intervention through local and national politics, policies, and individuals.

This paper reports the factors that impact Kenyan teacher’s beliefs, attitudes, and motivation to persevere in implementing a technology-based approach for literacy instruction and its potential to endure and expand to new contexts. The participants of this study were involved in the implementation of the software between 2012 and 2018. It started as a small pilot study with 12 primary teachers and their students and spread to more than 500 classrooms in five areas in Kenya (Abrami et al., 2016; Lysenko et al., 2019).

Method

About ABRACADABRA

As part of Learning Toolkit Plus, a suite of five bilingual (English and French) evidence-based and evidence-proven tools designed to build essential educational competencies, *ABRACADABRA (ABRA) software* is an online interactive environment promoting the teaching and learning of English and French literacy skills among youngsters, especially those at risk of school failure (Abrami et al., 2020). Figure 1 reflects the structure of the software. ABRA has three main modules: Students, Teachers and Parents—with the Student or instructional module being the main focus. Using a web browser, teachers and students access the software stored centrally on a server with a username and password. Thus, student activity may be tracked and organized in the form of teacher assessment reports accessible via the Teacher module.

ABRA contains 33 pre-alphabetic, alphabetic, fluency, comprehension, and writing activities of different levels of difficulty that are linked to a multitude of interactive stories of various genres. Students receive meaningful audio-visual feedback as they complete activities, guiding them to the correct answer. Activities are not timed, and children always have access to a help button. The gaming elements of ABRA are many and engage children in reading and writing to increase their motivation. For instance, a mini-game rewards students after they complete an activity. In some activities the game is at the core of their pedagogical structure. ABRA characters are linked to literacy skills; each has a personal story that reinforces the purpose and context of what students do in a specific activity.

The Teacher module contains a wide range of online support materials including lesson plans, teacher guides, instructional videos, and classroom resources. The Parent module offers websites that may be accessed from within or outside of the tool with an array of multimedia materials that help parents support use of the tool at home.

READS, an organized collection of illustrated digital stories from around the world, complements ABRA. The stories are in a variety of languages, including Kiswahili among others. Available in html or PDF formats, stories are catalogued by reading level, theme, language, country of origin, among other criteria. The library is easy to navigate, even for school-age children.

Figure 1

ABRA Structure

Training and supporting teachers of early grades on how to use ABRA to teach literacy is another key component of the intervention. The participating Kenyan teachers are mostly from under-resourced public schools. The teacher professional development (TPD) sessions are led by the local team of experienced trainers who rely on a variety of training approaches to introduce the ABRA pedagogy. While modelling effective lesson planning, using classroom simulation and feedback for and by the teachers, the trainers support the teachers by offering opportunities for transferable pedagogy through active participation and practice. The teachers are supported by school-based ambassadors (SBA) who are seasoned teachers and users of the software. The SBAs provide in-class support to peers, observe, and review lessons for future improvement. They communicate with the project coordinator to make plans for the follow-up monthly training where teachers reflect on their progress. Once the teachers gain sufficient confidence, the trainers and SBAs often go into the classrooms to observe lessons and give feedback to the teachers. This combination of face-to-face input and practicum-based activity continues cyclically through the implementation phase of the project.

Interview

In order to explore factors influencing the ABRA use based on the existing research, we designed the Sustainability Interview. The funnel format of the interview obtained the interviewees' broad and specific perceptions. The survey was piloted with a handful of individuals involved in the ABRA implementation since the onset of the research project in Kenya. The survey was then adjusted to elicit more specific responses.

The survey begins with two questions about how teachers got involved with ABRA and what they would have done differently to improve the software implementation. Then two broad questions inquire about ABRA's sustainability and scalability.

We consider teachers' expectancy beliefs to be in the larger context of potential influences and often beyond their control. Therefore, the survey explores eight categories of influences including Political Factors, Economic and Technology Factors, Organizational or School Factors, Teacher Professional Development Factors, Software Factors, individual Teacher and Student Factors, and other factors. Each question on the specific factors includes prompts to further probe respondents' thinking. For instance, the software factors question probed into how the ABRA fit with the curriculum, local context of stories and activities, narration and accents, the tool's interactivity, shortcomings, inadequacies, and gaps of the tool.

Sample

Forty-three individuals participated in the interview. Three interviewees participated in both phases of the survey; their pilot interviews were not included leaving 40 respondents in the analysis.

Table 1 shows the categories of respondents where school practitioners were the largest category. Of the 11 teachers, nine were active users of ABRA, whereas two stopped using the tools. Among five school administrators, four were the headteachers in the schools where use of ABRA continued over many years. The ambassadors were all school teachers; two of them were school-based and the other five were roving ambassadors.

Table 1

Categories of Interviewees

Interviewees	Number of Completed Interviews
School Practitioners:	
Head teachers, Deputy head teachers	5
Teachers	11
Ambassadors (master teachers)	7
Partners:	
I Choose Life staff (county coordinators, advisor, coach)	4
World Vision	3
Aga Khan Foundation, Development Network	2
Executive officers	3
Kenya project coordinators	3
Researchers	2

Analyses

After the interviews were transcribed, three respondents were randomly selected and their responses were used to develop a coding system. At this stage, the first author developed the system and elaborated on differences between expectancy, value, and cost statements. The three authors reviewed these codes and the coding system for finalization. Coding was completed with Hyper Research v.3.7.3. In addition to an a priori approach, data-driven codes were also generated. The second coder validated codes and their categorization on 10 randomly selected interviews. The agreement rate evolved from 59% to 85%.

Next, SPSS v.24 was used to quantify and analyze the data. We accounted for each of the factor categories, the sub-questions mentioned by a respondent, and the valence of the response as influencing the sustainability of the ABRA. Then, the total positive, negative, and neutral responses were cumulated across respondents. Only a single response per category and each subcategory were recorded to maintain the respondent as the unit of analysis. Multiple responses per category or subcategory were combined to reflect the coder's best impression of the respondent's beliefs. Finally, path analysis (AMOS v.26) was run to explore the relationship between expectancy-value-cost beliefs and the specific factors associated with implementation and sustainability.

Results

The findings are reported by the survey questions and followed by the path diagram results.

Reasons for Continuing or Stopping to Use the ABRA

All 40 respondents answered this question; each respondent offered up to 14 ideas. According to the theoretical framework, the ideas were grouped into values, expectations, and costs. The results are shown in Table 2.

Values related to benefits teachers saw after having used ABRA. The values category was the largest with 140 instances. Primarily, these pertained to benefits for their students as follows: they became more motivated (n=14), improved skills (n=12), and developed autonomy (n=12); students' absenteeism reduced (=4). Benefits for the teachers included motivating their students (n=11) and providing an opportunity for improving teaching expertise (n=10). General advantages of ABRA were its fit with the curriculum (n=6), comprehensiveness (=4), and effectiveness for students of various levels and abilities (n=4).

Expectations were categorized in the internal or external attributes in teachers' assigned perceptions. The most frequently reported internal attributions were "if teachers see value in using the tool" or "if the tool is not perceived as an add-on" (n=16); and if teachers are intrinsically motivated (n=10). Curiously, non-teacher interviewees indicated that technology use might be contingent on the teachers' age as younger teachers might be more tech savvy (n=5). Attributions to external sources were more frequent and related to school context: if headteachers are encouraging and do not hamper use (n=23); and if support is accessible (n=13); if electricity is stable (n=12). Expectation of a financial reward was also mentioned (n=4).

Table 2

Summary of Codes by Values, Expectations, and Costs

Categories (Number of Ideas)	Number of Respondents	Number of Coding References	% of Total Coding References
Values	*39*	*140*	
Benefits to students (12)	32	88	62.86%
Benefits to teachers (6)	21	32	22.86%
General benefits (7)	16	20	14.29%
Expectations	*39*	*111*	
External attributions (13)	30	61	54.95%
Internal attributions (8)	26	50	45.05%
Costs	*36*	*88*	
Psychological demands (5)	7	8	9.09%
Physical demands (16)	35	80	90.91%

Costs related to using ABRA was the smallest set including 88 instances where 91% were assigned to physical demands such as using the software outside class time since ABRA is not part of the curriculum (n=22); having plan B if technology fails (n=15) or there is no electricity (n=9); or managing technology use in big classes (n=7).

Major Challenges to Widespread Use of ABRA

Each of the 40 interviewees provided up to 18 ideas about the impediments to scaling ABRA in Kenyan schools (Table 3). Unreliable technology and infrastructure in schools (n=38) and lack of technical support at schools (n=17) were most frequently reported school-related challenges whereas rival programs and tools supported by the government (n=15) pertained to the system-related factors.

Among teacher-related challenges, the most frequently reported were technophobia and lack of ICT skills (n=29) and lack of interest in technology-based programs (n=19).

Table 3

Summary of Codes by Challenges to Scale

Categories (Number of ideas)	Number of Sources	Number of Coding References	% of Total Coding References
Total	*40*	*218*	
ABRA related (3)	8	9	4.13%
School-related (20)	39	100	45.87%
System-related (9)	13	17	7.80%
Teacher-related (24)	29	92	42.20%

Political Factors

Thirty-five respondents provided between one to eight comments about political influences on viability and scalability of ABRA tools in Kenyan schools (Table 4). Curiously, teachers offered considerably fewer opinions than school administrators and partners. Of the 121 instances, 65 pertained to the positive influences whereas 56 related to the impediments. We grouped policy-related factors as related to the context for the intervention, local and national governments' engagement with the ABRA implementation, and the potential outcomes of this engagement.

Table 4

Summary of Codes by Political Factors

Categories (Number of Ideas)	Number of Sources	Number of Coding References	% of Total Coding References
Total	*35*	*121*	
General educational system policies (20)	31	46	38.01
Local government (3)	14	15	12.4
Engaging government (5)	20	20	16.53
Benefits for the project (12)	29	40	33.06

According to the interviewees, the role of government for sustainability and scale of the intervention is paramount (n=20). Thus, ABRA should be part of the national curriculum (n=20), included on the Kenyan cloud, and authorized as the Digital Literacy Program content accessible on the government-provided tablets. However, some respondents (n=5) felt that government is protective of those initiatives they have developed from the beginning. This is why building the government's trust in the value and relevancy of ABRA is critical for sustainability and scale.

Economic and Technology Factors

All interviewees commented on the potential influences of economic and technology factors (Table 5). A computer-based pedagogical intervention might be affected by the school economies such as limited school budgets to cover expenses (n=12) and ever-growing costs such as technology repairs and electricity bills (n=13). In this context, the government's funding and support towards ICT in schools is critical (n=15), as are parent contributions to school budgets (n=11). Although, funds for technology should be earmarked (n=11). Poverty as a system-related factor affecting implementation was mentioned once.

Table 5

Summary of Codes by Economic and Technology Factors

Categories (Number of Ideas)	Number of Sources	Number of Coding References	% of Total Coding References
Total economic factors	*35*	*88*	
System-related (5)	19	21	23.87
School-related (10)	48	67	76.14
Total technology factors	*37*	*125*	
Devices (10)	30	39	31.20
Infrastructure (5)	16	21	16.80
Support (8)	53	57	45.60
Modernization (4)	5	8	6.40

Perceptions about technology factors varied. For instance, student-computer ratio of three or four students per device seems to be an acceptable index of access to technology (n=13). One interviewee noted that this ratio was optimal in big classes where the teacher would be exhausted if they had to attend to each student working on the teacher's device. On the contrary, this indicator was commented as too high to adequately expose their students to the tools, suggesting that it should be one student per device (n=5).

Further, unstable infrastructure and electricity supply (n=13), and lack of peripheral devices/headphones (n=10) were most frequently reported to slow down implementation. The respondents' opinions about technical service and maintenance available to schools were mixed: 10 respondents were satisfied whereas 12 were not happy. Limited technology support may have impacted the choices some school administration made because some kept computers in storage as they feared being personally accountable for broken devices.

School Factors

As Table 6 shows, the question about school and organizational factors stirred the most reactions (n=300). Each interviewee offered up to 15 ideas that pertained to leadership, concerted actions and coordinated activities on implementation, school-based expertise, and available technology.

Leadership was the critical factor for implementation (n=25). Encouraging ABRA instruction (n=14), visiting and observing classes (n=7), and following up when ABRA is not being used and thus applying pressure to do so (n=5) are the actions expected from the school leader. To be leaders, school administrators should not only understand the importance of technologies for teaching and learning (n=14) but they need to be trained in ABRA (n=7) and leadership strategies (n=5). Training might be a strategy to address administrators' resistance to change (n=7).

Table 6

Summary of Codes by School Factors

Categories (Number of Ideas)	Number of Sources	Number of Coding References	% of Total Coding References
Total	*40*	*300*	
Administration and leadership (26)	47	132	40.67
Concerted actions (23)	45	113	37.67
Scheduling (6)	20	27	9.00
Expertise (13)	25	35	11.67
Available technology (1)	1	3	1.00

It takes a whole school to implement a successful ICT programme, including a concerted effort to build ownership (n=15), collegial decision-making about its implementation (n=9), and the involvement of parents (n=16). Scheduled implementation and support activities should include uses of ABRA whether in the school lab or regular classroom (n=11), time for teachers to learn the tools (n=8), to share (n=10), and to support each other (n=6). School-based ambassadors are noted as experts capable of adequately supporting implementation (n=16).

Professional Development Factors

Each of the 35 respondents shared up to 15 ideas about teacher professional development (Table 7). Interestingly, four respondents (not teachers) provided one-third of all comments. Training was central in the model of ABRA-related professional development (n=10). The comprehensive nature of ABRA training was noted for its potential to make up for the gaps in the Digital Learning Program (DLP) training and target multiple stakeholders involved in implementation, including school administrators (n=4) and ambassadors (n=6).

Table 7

Summary of Codes by Professional Development Factors

Categories (Number of Ideas)	Number of Sources	Number of Coding References	% of Total Coding References
Total	*35*	*131*	
Training: general (10)	14	19	14.51
Training: outcomes (16)	21	32	24.43
Training: modes (5)	19	24	18.32
Training: accreditation (4)	7	11	8.40
Follow-up support (14)	21	45	34.35

Respondents also commented on the content and desired outcomes from training (n=32). In addition to developing an understanding of the tool and how to use it, training emphasizes the fit between ABRA tools and other programs; training also presents the comprehensive view of ABRA teaching logic; and improves instructional flexibility and capacity to make informed decisions about the tool to use. It targets a range of broader skills, including managing group work, teaching with ICT, and reflecting on teaching.

Offering certification in ABRA pedagogy is valued (n=11) as the evidence of professional growth, as a means to promotion, with marks on teacher appraisal or as a symbolic reward. There was an expressed need for structured follow-up (n=17) with ambassadors as the critical driver (n=9). To support teachers in small schools and remote areas, building the ABRA network was suggested (n=8).

Software Factors

In regard to ABRA software, the interviewees' highlighted the unique place that it takes in the instructional landscape and, therefore, its potential to bridge the existing gaps in the curriculum (n=14). Specifically, ABRA's flexibility makes it distinct in comparison to the prescriptive approach used in previous national programs targeting foundational skills in early reading (TUSOME, in Kiswahili Let's Read). Furthermore, ABRA targets specific skills versus general nature of the traditional instruction. Finally, READS library offers a wide range of resources in English and some in Kiswahili.

Table 8

Summary of Codes by the Software Factors

Categories (Number of Ideas)	Number of Sources	Number of Coding References	% of Total Coding References
Total	*40*	*235*	
Bridges gaps (7)	22	14	5.96
Inadequacies (14)	25	42	17.87
Effectiveness (13)	28	42	17.88
Content (13)	22	38	16.17
Fit (7)	32	48	20.42
Design and features (19)	22	35	14.90
Student-centeredness (5)	10	16	6.81

The fit between ABRA and educational context including the Competency-Based Curriculum, its goals, and teaching schemes was reported most frequently (n=46). ABRA is well aligned with the paper-based national programs and reinforces these programs as interactive learning technology that works on the government-provided tablets. ABRA interactive content was commented to offer more than existing curricular materials and textbooks (n=21). In addition to interactivity, game-like design, potential for differentiated instruction, and interoperability of the software on various devices and platforms were notes. Student-centeredness of ABRA was important (n=10) as it supports student autonomy, enables learning at one's own pace, and teaching each other.

ABRA effectiveness was commended (n=27). The tools generate evidence of learning progress, enable teachers to motivate students, and stimulate interest yielding important learning gains. After being exposed to the tools, younger students outperform older ones. Further, students continue to be interested in using ABRA even after they used it for some time.

Interviewees also commented about inadequacies noted in ABRA tools. They noted lack of fit with the local language context, including accent, no access to the tools from home, lack of reading activities for older students, and ambiguity in the meaning of some concepts introduced in a tool were reported.

Individual Teacher Factors

Thirty-five participants commented about the teachers who would be inclined to teach with ABRA (Table 9). Interestingly, the teacher-interviewees gave minimal opinions on the matter. Overall, the comments focused on dispositions and skills that the teacher-user of ABRA possesses.

Table 9

Summary of Codes by Individual Teacher Factors

Categories (Number of Ideas)	Number of Sources	Number of Coding References	% of Total Coding References
Total	*35*	*175*	
Self-determination (1)	1	1	0.57
Self-efficacy (4)	18	22	13.57
Dispositions (29)	48	104	59.43
Skills and abilities (11)	21	31	17.71
Self-efficacy sources (2)	9	9	5.14
General observations (2)	2	2	1.14
Teacher age (1)	6	6	3.43

Being the most important factor (n=29), the dispositions of the ABRA teacher include professional interest (n=12) and confidence, using ICT (n=11), ability and readiness to get out of the comfort zone (n=7), and passion (n=5). Teacher readiness to do extra work (n=6), commitment (n=3), and persistence (n=3) were also noted as drivers of sustainable use. On the opposite side of the spectrum are the teachers described as passive (n=7), technophobic (n=6), or questioning the purpose of teaching with ICT (n=3).

Contrary to the factors arising from the affective domain, teacher capacity and skills were less reported. They include ability to use ICT and integrate it in instruction (n=12), ability to train others (n=4), and self-teach (n=2). The arrival of a new generation of tech-savvy teachers was noted as a potential turning point for a large-scale acceptance of technology-based interventions (n=6).

Individual Student Factors

The comments about student factors that may affect teaching with ABRA were rare (Table 10). Only 19 respondents, either a teacher or a school administrator, expressed up to seven ideas. These rather related to the gains students got as a result of learning with ABRA tools and included the increase in student autonomy (n=10), engagement (n=9), and interest to learning (n=6). Together with improvements in student learning (n=6), progress in students' social skills, perseverance, capacity to peer-teach and even readiness to teach teachers were reported.

Table 10

Summary of Codes by Individual Student Factors

Categories (Number of Ideas)	Number of Sources	Number of Coding References	% of Total Coding References
Total	*19*	*70*	
Disposition (6)	11	16	22.86
Skills and abilities (9)	13	16	22.86
Benefits for students (7)	23	38	54.29

Some respondents stated that weaker students required more time to learn with the tool. Others suggested that student individual differences did not matter, instead it is the teachers' capacity to implement the tool that counts (n=3). At the same time, successful ABRA students are tech savvy and excited by ICT (n=11).

Factor Effects

We also investigated what factors might have influenced the teachers' intent to continue or stop using ABRA in their practice. First, we applied the expectation-value framework which reduces teaching with technology to a simple teacher motivation equation (Wozney et al., 2006). The composite variable of the teacher Motivation to Sustain ABRA Use was created by aggregating the number of coding references within each of the three categories of value (M=3.05, SD=2.22), expectations

(M=2.75, SD=1.90), and costs (M=2.13, SD=1.59) per respondent and letting them enter the equation expectancy + value - cost of use. The resulting motivation mean score and the standard deviation were 5.25 and 3.76 respectively (Table 11).

We calculated continuous composite scores for the eight factors by combining together the subcategories within each factor. We hypothesized that the factors directly predict practitioner's intent to continue or stop using ABRA. Additionally, we assumed that Teacher Factors can be directly predicted by Professional Development, Student, and School Factors and serve as an intervening variable between the three sets of factors and teacher motivation to sustain the ABRA Use. The correlation coefficients support this assumption (Table 11) showing significant positive relationship between a) PD, School Factors, and Teacher Factors, and b) Teacher Factors, PD, School Factors, and Motivation to Sustain ABRA Use.

Table 11

Means, Standard Deviations, and Correlations of Eight Factors and Motivation to Sustain Using LTK

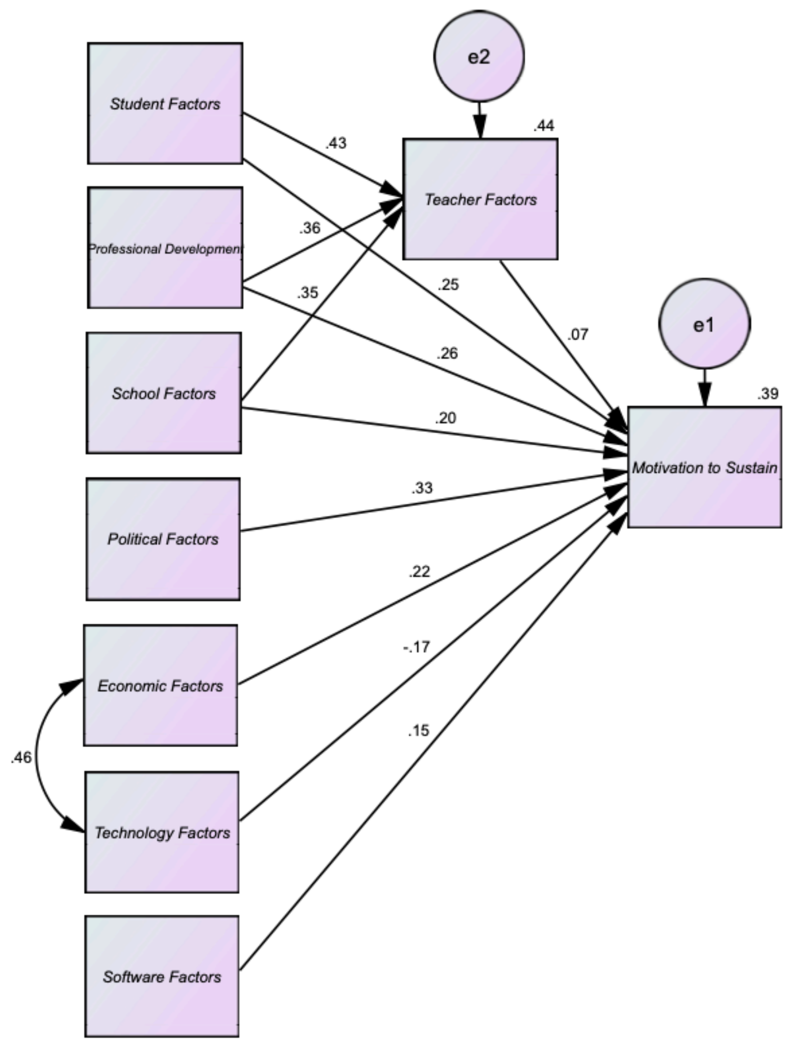
	1	2	3	4	5	6	7	8	M	SD
1. Motivation to sustain use of LTK									5.25	3.76
2. Economic Factors	.154								2.20	1.85
3. Technology Factors	.092	.462**							2.90	2.45
4. Political Factors	.231	.070	.302						1.85	1.61
5. Software Factors	.107	-.025	.208	.204					5.55	3.49
6. School Factors	.322*	-.124	-.109	-.113	.141				7.30	3.81
7. PD Factors	.363*	.017	.039	-.011	.047	.297			3.15	3.11
8. Teacher Factors	.351*	-.058	.254	-.018	.096	.483**	.444**		4.33	3.94
9. Student Factors	.297	.068	.092	-.051	.066	.111	.009	.449**	0.65	0.98

Note. **p< 0.01; *p< 0.05

AMOS path analysis generated support for the hypothesized model with the chi-square index of 25.905 (df=24), p=.358. The Goodness-of-fit indices also implied a reasonably well-fitting model. The Comparative Fit Index (CFI) of 0.96 was robust. The Root Mean Square Error of Approximation index (RMSEA) was 0.045 (p=.458) with the confidence intervals of 0.000 and 0.140. Such combination of RMSEA and confidence intervals suggest an acceptable precision of the model. There was no evidence of the model misfit. Two modification indices (MI < 20; parameter change < .10) suggested that the hypothesized model is appropriately described; the highest standardized residuals was 1.88 below critical value of 2.58. The hypothesized model is in Figure 2; the model effects are in Table 12.

Figure 2

Effects on Teacher Motivation to Sustain Use of LTK Path Model



The eight factors accounted for 39% of the variance in the motivation to sustain ABRA use. The effects of the seven exogenous factors within the model were mixed. Increased motivation to sustain the use of ABRA was significantly predicted by Policy and Professional Development Factors, the standardized coefficients were 0.34 and 0.27 respectively, whereas the remaining five factors did not have significant direct effects.

Table 12

Decomposition of Effects

	Factors							
	PD	Student	School	Teacher	Political	Economic	Technology	Software
Standardized direct effects								
Teacher Factors	0.359*	0.431**	0.355*					
Motivation to Sustain ABRA Use	0.265*	0.245	0.204	0.065	0.335*	0.220	-0.172	0.151
Standardized indirect effects								
Motivation to Sustain ABRA Use	0.023	0.028	0.023					
Standardized total effects								
Motivation to Sustain ABRA Use	0.288*	0.274*	0.227	0.065	0.335*	0.220	-0.172	0.151

Note. **p< 0.01; *p< 0.05

Except Technology Factors whose effect was negative, the other factors' influences were positive. Student, School, and Professional Development Factors each had a strong direct significant effect collectively explaining 46% of variance of the only moderator, Teacher Factors. The respective coefficients were 0.43, 0.35 and 0.39. Yet, Teacher Factors minimally contributed to the variation in a teacher's intent to sustain the ABRA use (β=0.065). After controlling for the mediator, the indirect effects of the Student, School, and Professional Development Factors on the intent to sustain use were positive but small and not statistically significant. The total effects were statistically significant for Political, Professional Development, and Student Factors implying that each one-point increase in reporting them would rise motivation by 0.34, 0.29 and 0.27 per unit respectively. Except for the strong and significant relationship with Teacher Factors, School influences were not significant for the Motivation to Sustain the Use of ABRA; neither were Economic, Technology and Software Factors.

Discussion

This paper reports the findings from the interviews of 40 schoolteachers and headteachers, and partners involved in implementing the ABRA. We explored their perceptions and experiences about the factors believed to influence adoption and further use of this educational technology. The individual teacher's agency in making the difference in the classroom, the school, and eventually, the whole system is the cornerstone of this study. However, implementing an innovation with quality and efficiency, and then sustaining it and, eventually, bringing it to scale, are subject to many challenges and opportunities. In our model, three set of influences, Political, Teacher Professional Development, and Student Factors, accounted for the teachers' self-reported intent to teach with ABRA.

Political context shaped by government, unions, parents, and other interest groups turned out to be the most influential antecedent for the teachers' decision to implement and sustain the program. In this regard, it was critical to demonstrate to teachers how ABRA fits the educational landscape and helps achieve national educational objectives brought in by the massive curricular reform and the technology initiative (DLP). More efforts are yet to be made in order to build the government's trust in the value and relevancy of ABRA, which is critical for the program sustainability and scale.

Professional Development Factors had important effects on teacher motivation, skills, and dispositions. Participation of expert users of ABRA such as trainers and school-based ambassadors in the system of training and follow-up support benefited teachers and, especially, neophytes. Expert users modelled ABRA for school contexts and addressed the uncertainties of those just starting out by illustrating experts' success in beginner-like contexts. In addition to experts, teachers gained from peer learning where they planned ABRA instruction, shared experiences, and reflected upon them. Since formal ABRA certification helped the progression of teacher career, it contributed to their motivation too. Yet, it also might be that teachers saw TPD as an opening to escape drudgery of their classrooms.

The influence of Student Factors was important on teacher motivation. Students' experiences with the software increased their autonomy, engagement, and interest in learning drove their teachers' enthusiasm and intent to continue using the tool. Further, students' vocal support of using the software for teaching might have prompted teachers to improve their capacity and effort to integrate ABRA in instruction.

Despite the important contribution from students, professional development opportunities and school environment in teacher factors including skills and competencies, the effect of Teacher Factors on motivation to sustain teaching with ABRA was non-existent. Indeed, skills and competencies can potentially drive changes in practice but only to a limit. Salinas et al. (2017) suggest that while many teachers become involved in innovation because they feel their personal effort is worthwhile regardless of whether they receive support from the system, yet a longstanding change cannot be maintained through teacher commitment alone. For if the effort must be sustained for too long, it is likely that the enthusiasm of these teachers will wain and they will no longer be able to sustain a complicated process of the innovation use. As a result, teachers may assign greater importance to the centralized system and its policies, rather than their own capacity and skill. We can only speculate that the important weight assigned to policy factors and lack of weight assigned to teacher factors in the teacher intent to implement ABRA reflects the tension between external and internal agency needed to drive change in teacher practices.

Conclusion

The usefulness of these findings is three-fold. First, these results are practical in the context of developing countries where little is known about the evidence-based principles of building sustainable and scalable educational interventions (Robinson et al., 2017). The existing research tends to follow the evolution of relatively large initiatives into educational mainstream while learning about how a small intervention proven successful with a handful of teachers and students can grow to reach many in dire need of it stirs less interest in educational development research. Second, the tested model validated the results from the qualitative interviews, suggesting paths associating a range of external and internal factors with teacher motivation to implement ABRA. Yet, it is also likely that other factors not included in this model, such as measurement error, coder bias, and small sample size, had their effects. Third, the model points to the priority directions for technology-based pedagogical innovations to endure and expand in developing contexts. This includes seeking instrumental support from the local and national stakeholder agencies and enhancing teacher professional development in order to strengthen individual and collective teacher capacity.

Finally, since spreading beyond a few schools raises strategically different issues for the project, the results of this study suggest the need to advance our research agenda. For instance, further validation of the model is important. Hence, a pool of around 500 teachers who either continue or stopped teaching with ABRA could be targeted by an online close-ended survey based on this interview. Substantially, it is necessary to learn how we could effectively thread the ABRA-related ideas throughout the local and national educational authorities to establish their long-term support and ensure that the activities fit the short- and long-term strategies of these authorities even if their priorities change. To this end, it is also important to build the cost-effective TPD and support system as the critical multiplier to scale the ABRA program. After all, in the constraints of low- and medium-income contexts, the practical value would be assigned to an innovation when it functions at minimal costs without losing its impact on teacher practices and student learning.

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Analysing an Interactive Problem-Solving Task Through the Lens of Double Stimulation

Analyse d'une tâche interactive de résolution de problèmes sous l'angle de la double stimulation

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Abstract

Problem-solving activities have been studied from a diversity of epistemological perspectives. In problem-solving activities, the initial tensions of a problematic situation led to a cognitive dissonance between conflicting motives and instruments to reach the activity goal. We analyze problem-solving in the continuation of Sannino and Laitinen's (2015) approach to the analysis of a decision-forming apparatus. The originality of this study is in consideration of the materialistic nature of double stimulation that appears during the activity of the CreaCube problem-solving task. This activity engages the participant in solving tasks with interactive robotic instruments. To solve a task, the subject is required to build interactive robotic modules into a specific configuration which will cause the artifact to move from an initial position to a predetermined final position. The conflict of stimuli in the CreaCube is strong and observable because of the tangibility of the artifact, which is manipulated by the participant into different configurations with the goal of solving the task. We discuss double stimulation in relation to the artifactual interactive affordances of educational robotics.

Keywords: Conflict of stimuli; Double stimulation; Educational robotics; Decision-forming apparatus; Problem-solving

Résumé

Les activités de résolution de problèmes ont été étudiées à partir d'une diversité de perspectives épistémologiques. Dans les activités de résolution de problèmes, les tensions initiales d'une situation problématique ont conduit à une dissonance cognitive entre des motifs et des instruments contradictoires pour atteindre le but de l'activité. Nous analysons la résolution de problèmes dans le prolongement de la démarche de Sannino et Laitinen (2015) pour l'analyse d'un appareil de formation de décision. L'originalité de cette étude réside dans la prise en compte de la nature matérialiste de la double stimulation qui apparaît lors de l'activité de la tâche de résolution de problèmes CreaCube. Cette activité engage le participant dans la résolution de tâches avec des instruments robotiques interactifs. Afin de résoudre une tâche, le sujet doit construire des modules robotiques interactifs dans une configuration spécifique qui fera bouger l'artefact d'une position initiale à une position finale prédéterminée. Le conflit de stimuli dans le CreaCube est fort et observable en raison de la tangibilité de l'artefact qui est manipulé par le participant dans différentes configurations dans le but de résoudre la tâche. Nous discutons de la double stimulation en relation avec les affordances interactives artefactuelles de la robotique éducative.

Mots-clés : Conflit de stimuli ; Double stimulation ; Robotique éducative ; Appareil de prise de décision ; Résolution de problèmes

Introduction

This paper focuses on an interactive problem-solving task mediated using modular robotics. Research in problem-solving presents many challenges, including the need to consider temporality and dynamic events through micro genetic approaches (Ludvigsen et al., 2018). Problem-solving is described as a process which develops through the four stages in the PISA framework for problem-solving (OECD, 2013), like the four stages defined by Polya (1985): a) identification of the problem, b) planning, c) developing actions toward a solution, and d) evaluating a solution. These stages are described as general behaviours, specifying neither the underpinning volitional processes nor the conflicting motives and stimuli during the problem-solving activity. To more deeply understand why and how an ill-defined problem is being solved, the relation between the subject's processes (conflicting motives, decision-forming process, agency, activity) and the specific task in which the participant is engaged must be pinpointed. Vygotsky's principle of double stimulation (DS) can be used as a lens to understand how subjects make sense of a complex problem (considered the first stimulus) and the process that they commit to pursue an activity as they construct a second stimulus bringing new meaning to the activity. Vygotsky's principle of DS, an epistemological principle in third-generation activity theory, is fruitful to understand how agency emerges when an individual constructs a second stimulus in response to a problem involving a conflict of motives (Sannino, & Laitinen, 2015). The DS principle "refers to the mechanism whereby human beings can intentionally emerge from a conflict situation and change the circumstances in which they find themselves or solve problems" (Engeström & Sannino, 2013, p. 6). The conflict is resolved by invoking a neutral artifact as a second stimulus which is turned into a mediating sign by investing it with meaning.

This study considers problem-solving as an activity developed by a subject engaged in an ill-defined task which presents a conflictual situation that constitutes the first stimulus. This stimulus is a necessary element to trigger transformative agency in response to a cognitive conflict (Engeström & Sannino, 2013, p. 4). To overcome the problematic situation, the subject must demonstrate agency in the form of building a second stimulus that will give new meaning to the situation and overcome the initial tensions of the problem situation. The building of the second stimulus is one of the key concepts in activity theory that is required to understand how subjects emancipate themselves from a given problematic situation. This approach to problem-solving considers the situation as a system. Despite the studies of decision-forming apparatus developed within the socio-cultural approach (Engeström & Sannino, 2013), this approach has not been developed in complex and systemic problem-solving tasks engaging technology as mediating tools. This study proposes to address this challenge and study a complex and systemic problem-solving task through the analysis of the decision-forming apparatus. Vygotskian activity theory perspective implies that we cannot consider the initial situation to be dealt with directly. Neither can such a perspective permit us to establish a plan to address the problem-solving process. Through reconfiguring of the initial situation and as a second stimulus is brought forward, the subject creates new meaning to the artifact that advances the problem-solving process. In the next section, we analyze the role of conflict of motives from the initial to the final stages of problem-solving.

The Key Role of Conflicts of Motives

The principle of double stimulation considers all initial tensions in the problem situation as a necessary foundation; conflicting stimuli lead to conflicting motives, which produce cognitive dissonance. Conflicting motives can be expressed in the form of dilemmas and double-binds and can be even paralyzing if they are not prioritized (Engeström & Sannino, 2011). The conflicting motives emerging in an ill-defined problem-solving task are essential to trigger the decision-forming process (Barma et al., 2015). Conflicting motives are also considered from the neuroscientific perspective under the term of concurrent goals (Charron & Koechlin, 2010) whereby the subject is required to evaluate the different goals and motives in a certain context. Within the problem-solving task, the subject engages in different decision-making processes that are subordinated to the different goals and motives. From a neuroscientific perspective, problem-solving is dynamic and engages a self-correcting process of the actions within the activity.

The materialist aspect of the educational robotic task requires us to consider not only language as a mediating tool but also studies which have been addressing manipulative tasks in robot computer interaction (Norman, 1986), but also recent works in neurosciences related to value-based decision making (Rangel et al., 2008). From Rangel and colleagues' perspective, the subject updates the value of an action as they advance in the problem-solving process. Solving conflicting motives is an important aspect of that process that needs to be addressed before engaging in the task and throughout the entire process as the task progresses toward a final resolution. Despite the overly simplistic view of acceptance of the task instruction and engagement on the task, both Vygotskian and neuroscientific approaches consider the human to have multiple and conflicting motives before and during a certain task. Sannino and Laitinen (2015) point out that in one of his texts, Vygotsky (1997) brings to our attention how the emergence of "volitional action by means of auxiliary stimuli and involving a conflict of motives as a central component" is key in self-control (p. 6).

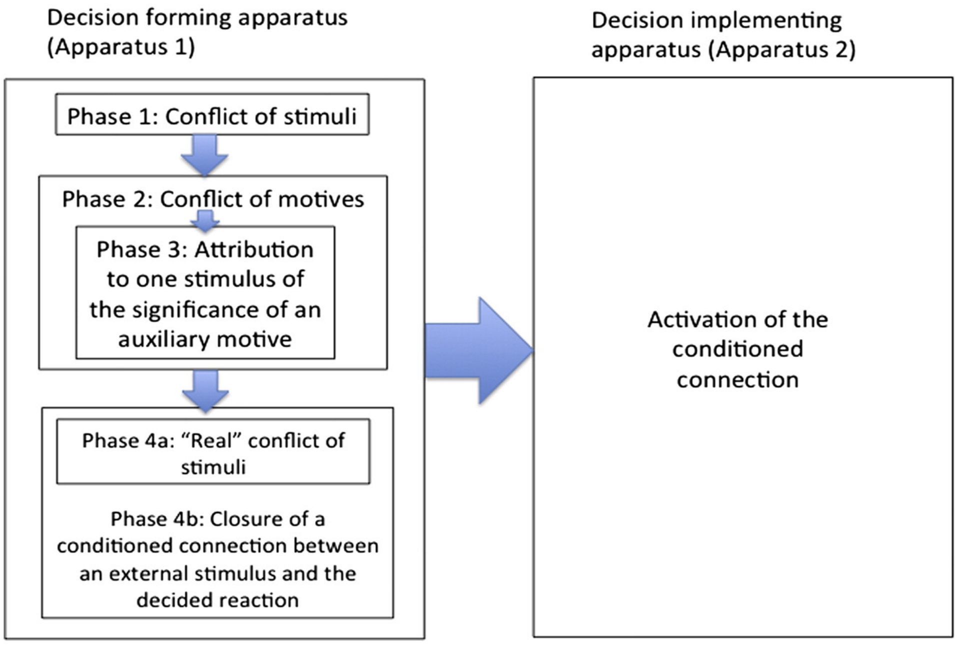
Presenting an ill-defined task to participants may create instability and insecurity in the form of cognitive dissonance (a first stimulus). Double stimulation can also be used as a methodology to elicit agency as well as a theoretical framework that will enable a better understanding of the process of building higher mental functions. Vygotsky's principle of DS can help us better understand how agency emerges when a person constructs a second stimulus in response to a problem involving a conflict of motives. To break away from a situation of conflict of motives, agency needs to emerge. Agency refers to "the subject's willed quest for transformation. It transpires in a problematic, polymotivated situation in which the subject evaluates and interprets the circumstances, makes decisions according to the interpretations and acts upon these decisions" (Engeström & Sannino, 2013, pp. 3-4). The conflictual situation constitutes the first stimulus and is a necessary element to trigger transformative agency (Engeström & Sannino, 2013) to internalize, create and use new mental functions to break away from a paralyzing situation (Engeström, 2007).

Conflicts of motives resolution have often been analyzed in time periods going from a few days to weeks; nevertheless, the resolution of the conflictual motives can also be applied in much shorter periods of time. Sannino and Laitinen (2015) develop their results in the context of the waiting experiment, which happens in minutes. The "waiting" is considered "a state of oscillation, confusion, and indecisiveness for some time" (Vygotsky, 1987, p. 356). Through the waiting experiment, Vygotsky (1997) observes the emergence of volitional action. The actions that the subject develops to overcome the conflict become a second stimulus. Sannino and Laitinen (2015) describe the emergence of volitional action with DS as a process involving two apparatuses which "are relatively independent of each other" (p. 213) and also correspond to "two stages in the genesis of will" (p. 218). Figure 1 introduces the model of double stimulation by Sannino and Laitinen (2015).

- Apparatus 1 consists of deciding to act in a certain way with the help of an auxiliary motive (e.g., the striking of a clock).
- Apparatus 2 consists of implementing the decision-formed in Apparatus 1. Apparatus 1 is the most complex and can be depicted as involving four phases.

Figure 1

Model of Double Stimulation (Sannino, 2015)



Materialistic Dialectic and Affordances

Problem-solving with manipulable material engages the participant in a concrete interaction between the subject and the object. In these contexts, problem-solving is observable in the building process of the participant through the different configurations of the material during the problem-solving task. The tool proposed to the participants is a set of four robotics cubes engaging the participants to manipulate "visuo-spatial constructive play objects" (VCPOs) (Ness & Farenga, 2016) for building the different configurations during the problem-solving task. In the problem-solving tasks with manipulable VCPOs, activity theory can help in analyzing the *materialistic dialectic* to understand the process of interaction between the subject and the object. In the materialistic theory of activity, it is only this relation that is regarded as fundamental: the concept of activity necessarily includes the concept of its object. This is a constituent feature of activity that is concrete. Activity here is to be understood as purposeful activity and not as synonymous with process or continuum in general.

In their attempts to solve problems in the context of scientific practices like the ones of engineers, Nersessian (1984) proposes that concept formation and conceptual change arise from the interplay of conceptual and material resources provided by the problem situation. It does, however to a large extent, demand reflection on one's activities as a process of cognition. For Davydov (1990), a learning activity is a form of creative appropriation of knowledge and concepts. In that sense, knowledge cannot be understood without reference to activity, and activity cannot be understood as purposeless activity without reference to content (Fichtner, 1999).

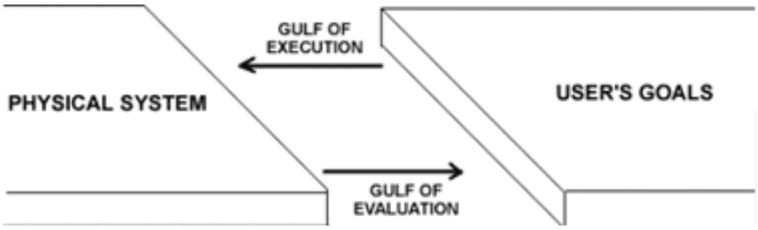
In problem-solving with tools to which the subject has not yet attributed contextual meaning to the task, we can refer to the work of Ilyenkov (2007) on materialist dialectics. Ilyenkov discusses the insoluble contradiction for which the usual methods of operations cannot provide an answer. From a neuroscience perspective, the ill-defined problem-solving situation does not allow the transfer of existing knowledge to solve the task but rather requires the exploration of the system in a new way. There is a contradiction in the way the subject goal can be achieved with tools available in the situation (Norman, 1986). In those conflicting problem-solving situations, the subject must be able "to formulate a contradiction and then find its real resolution through the concrete examination of the thing, the reality, (and not through) means of formal verbal manipulations that fudge contradictions instead of resolving them" (Ilyenkov, 2007, p. 21).

The term "concrete" refers to the functional relation of the activity system, and it "is reserved for a lawfully connected aggregate or real facts, or system of determining facts understood in their interconnection and interaction" (Ilyenkov, 2007, p. 33). Concrete is "rather the holistic quality of systemic interconnectedness" (Engeström, 2014, p. 191). We can consider "concrete" as a systematic and evolving state of the activity, in which instruments and actions are interconnected to solve the situation. The process of actualization of "concrete" at the subject level is influenced by artifact actualization through the enactment of the building of the second stimulus (second apparatus).

The concept of affordance is meaningful in understanding the artifact evolution through problem-solving activities with manipulatives. In problem-solving with tools to which the subject has not attributed meaning in the context of the task, the uncomfortable situation is also due to the impossibility of using the available tools to solve the situation in an already known way. According to Hutchins et al. (1985) and Norman (1986), a materialistic problem situates the subject in front of a *gulf of execution*, the distance between the user's goals and the means of achieving them through the system. The gulf of execution represented in Figure 2 should be crossed through the exploration of the means or tools available to the participant to achieve a certain goal or solve a certain problem situation (execution bridge) and evaluate the effectiveness of these actions (evaluation bridge). The actions of exploration of the artifact (physical system) can support the emergence of knowledge from the abstract to the concrete, but also, in interactive systems, the actualization of the artifact's configuration. Through this process of actualization at the user level and at the artifact level, there is an enactment of the building of the second stimulus (second apparatus).

Figure 2

Gulf of Execution as Distance Between User's Goals and Physical System (Hutchins et al., 1985).



Research Objective: Analysis of an Interactive Problem-Solving Task

This study focuses on a problem-solving activity mediated by educational robotic technologies. Additionally, the dynamic process of problem-solving is described in the context of a modular robotic task. The dynamic process is described through a materialistic dialectic with the principles of DS. For this objective, we analyze two case studies engaged in the CreaCube task and compare a child and an adult to study problem-solving from a broader developmental perspective. The Sannino DS model is unique in the sense that it allows apprehending an analysis through a generic lens. What the DS proposes is founded in Vygotsky's work, arguing that conflicts are at the core of problem-solving in a dialectical way. Building on Leontyev's (2009) reflections on conflicts of motives, Sannino (2015) emphasises that engaging in volitional actions is more than just about "choice and decision making" (p. 15). Making a choice supposes that "duality is at the very foundation of the volitional act, and this duality becomes especially prominent and vivid whenever several motives, several opposing strivings, clash in our consciousness" (Vygotsky, 1997, p. 167-168). Conflicts of motives are important components in Vygotsky's principle of double stimulation and key elements to trigger agency. They act as the first stimulus to begin the process of will formation (Barma et al., 2015; Sannino, 2015).

Methodology

Participants engage in the task through a well-established protocol. The cubes are initially covered while the participant is listening to the instruction. Fractions of the cubes are uncovered, allowing the subject to engage in the activity. There is no time pressure while doing the task; nevertheless, the experimenter is in front of the participant, and there is a video recording of their hands during the problem-solving task.

CreaCube Task

The CreaCube task aims to engage the participant in an ill-defined problem-solving task. The participant is exposed to unknown, hidden cubes which need to be manipulated to achieve the game's objective: creating an autonomous vehicle that eventually reaches the finish point (Romero, 2019). The CreaCube task has been designed as a problem-solving task in which the participant is engaged towards the objective of creating a vehicle that is able to move in an autonomous way from a starting red point to a final black point. The material components are four modular robotic cubes, selected from the *Cubelets* toolkit, considered build-bots composed of modular parts. Figure 3 shows a participant seated in front of a table, upon which there are four robotic modular cubes. The participants engaged in the CreaCube task notice the cubes' different colours, but they are required to engage in the manipulative exploration of each cube to notice further differences between cubes. The participant should grasp the cubes, manipulate them to understand their features, and experiment with different constructions to find a solution.

Figure 3

The Four Robotic Cubes at the Initial Configuration of the CreaCube Task

Instructions

Instructions for the CreaCube task engage the participant in creating a vehicle moving from a starting point (red point on the playmat in Figure 3) to a final point (black point on the playmat) by assembling four "pieces". The pieces are constituted of four different Cubelets modular robotic cubes.

Participants

The study is developed through two cases; the first case is a child in elementary school and the second case is a pre-service adult teacher. These participants have not previously played with the Cubelets toolkit. They are voluntarily engaging in the task presented to them as a game. The child solved the activity in 11 minutes 37 seconds while the adult solved it in 6 minutes 44 seconds.

CreaCube Task Material Artifacts and Characteristics

This study focuses on a problem-solving activity mediated by educational robotic technologies. The existing literature on materialistic dialectic has not been focused on educational robotics but on other types of artifacts (Nuttall & Brennan, 2016). In educational robotics, the interactive affordances introduce complexity to the problem-solving task. Each of the modular robotic cubes has different *visual affordances* (magnets, wheels, a switch, "two eyes" or holes) and *technological affordances*, which are features of the cubes that can be observed when the cubes are assembled. The red cube has six identical faces. The three other cubes have five identical faces and one specific face with a visual affordance: the black cube has two eyes which corresponds to the distance sensor feature (technological affordance), the dark blue cube has a switch which allows the provision of energy into the system, and the white cube has two black wheels which are the visual affordances for the servo-wheels allowing the system to move (technological affordance). To successfully configure the cubes so that they move autonomously from an initial point to the final point, the four cubes must be assembled in a specific way: the switch should be activated, the wheels should be in contact with the floor, and the red cube (inverter) should be situated before the black cube (distance sensor).

Figure 4

The Four Robotic Cubes Visual Affordances

In tinkering tasks, the tools are an important mediating factor in the problem-solving process (Parekh & Gee, 2019). Not only do the cubes need to be manipulated to be understood, but each has different features. These differences are part of the complexity of the task. The participant evaluates the initial problem based on the instructions inviting the participant to build a vehicle that can move autonomously (task goal) with the four cubes provided as a set of tools to build an artifact to solve the problem. This initial conflictual situation requires the participant to explore the tools to make sense of the task and build a second stimulus.

Due to the task's complexity, the configuration of the cube requires the participant to assemble and disassemble the cubes several times through a tinkering process in which the *objects-to-think-with* (Papert, 1980) engage the participant in a materialistic dialectic. The situation requires the participant to go beyond their current knowledge; they are required to be creative in establishing functional relations between the cubes' behaviour and the meaning given to the technological affordances that make each behaviour possible. The problem space is expected to be reduced when the participants establish meaningful functional relations contributing to advance toward a solution.

Results

The results start by introducing the decision-forming at the different stages of the problem-solving task: the initial stages of the child and the adult forming apparatus. The analysis is developed for each of the phases: conflict of stimuli (phase 1), conflict of motives (phase 2), attribution to one stimulus of the significance of an auxiliary motive (phase 3), real conflict of stimulus (phase 4a), and the closure of a conditioned connection between an external stimulus and the decided reaction (phase 4b). The results conclude by describing the DS as a meaningful approach to understanding creative problem-solving.

Decision-Forming at the Initial Stages of the Problem-Solving Task

Before engaging in an action to solve the task, the subject should identify the problem. At this stage of the task, the decision-forming apparatus of Sannino and Laitinen (2015) to describe the four phases of the decision-forming of the CreaCube task is considered. The analysis of the occurrences of the decision-forming apparatus of Sannino and Laitinen (*ibid*) in the experiments involving the child and the adult is described in the following tables and figures.

The analysis of the child decision-forming apparatus shows a non-linear iteration of the different phases, with a prevalence of phases 1 and 3 initially and phase 4 at the end of the activity. The conflict of stimuli appears through the task interaction and brings about the way the meaning is generated through the task. In Vygotsky's (1997) theory, an initial stimulus situation involves a conflict of motives. After the child receives the instructions, a conflict of motives (deciding to explore and touch the cubes versus not engaging) is observed prior to a conflict of stimuli (contact with the material physical artifacts). Even if it happens in a short period of time, the decision-forming Apparatus 1 details what can happen during the initial phase. Nevertheless, in the video analysis of the task, the conflict of motives is not identified. However, the tangibility of the task allows different loops of conflict of stimuli to be observed. The tangibility of the manipulated tools contributes to the rapid generation of conflict of stimuli. Additionally, it helps to advance towards the generation of new configurations contributing to learning expansion through the problem space to the problem solution.

Figure 5

The Child is Paralyzed in Front of the Cubes

Figure 6

The Child Starting to Build a Configuration by Assembling the Cubes

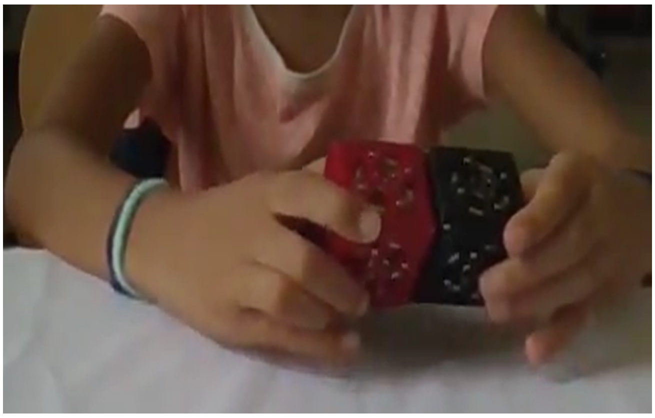


Figure 7

The Child Expands their Knowledge by Creating a New Configuration

The full process of the child decision-forming apparatus is described in Table 1.

Table 1

Analysis of the Child Decision-Forming Apparatus

Phase	Time	Observed Behaviour (Video analysis)
Phase 1. Conflict of stimuli	0 sec	The child listens to instructions.
	40 sec	The child evaluates the situation without touching the material (Figure 5). The child seems initially paralyzed by the conflict of stimuli between the instructions (task goal) and the tools to achieve the goal. The paralysis lasts 26 seconds.
	50 sec	The child explores the cubes and observes the differences among them. They move the cubes and bring them closer.
Phase 3. Attribution to one stimulus of the significance of an auxiliary motive	1 min 12 sec	At this stage, the child has attributed the wheels' affordance stimulus to a significant amount of movement. This attribution is meaningful for moving the object as proposed by the instructions. They have internalized the meaning of one of the features of the drive cube. From this moment on, they have attributed a partial meaning that brings them forward in the process of problem-solving, which constitutes a germ cell in terms of Engeström and Sannino (2010). Germ cells contribute to bridging the gap between the initial situation and the solution of the problem activity.

Phase	Time	Observed Behaviour (Video analysis)
		Once the person catches the germ cell related to the wheels' feature, the activity system will no longer be the same, and the participant is a step closer to the solution. The germ cell is developed through the interactions between the subject and the educational robotic tools proposed to be reconfigured towards the object of the task.
Phase 1. Conflict of stimuli	1 min 14 sec	Even though the child found the wheels' *visual affordance*, the wheels do not react as they intended (*technological affordance*).
	1 min 19 sec	The child starts assembling the cubes and realizes the cubes are magnetic. They start trying to randomly connect the cubes to build a vehicle.
Phase 1. Conflict of stimuli	2 min 5 sec	After trying to solve the conflict of motives by assembling the cubes, they then return to the initial stage of conflict of stimuli and start exploring the cubes individually again. They focus on the wheels' affordances and confront the expectations of technological affordances by making the wheels move with their fingers and through a friction movement on the table.
	2 min 18 sec	The child engages in iterations of conflict of stimuli. They engage in different ways of assembling the cubes in a trial-and-error behaviour looking to generate new stimuli for overcoming the conflict of motives. Nevertheless, these iterations do not permit overcoming the situation.
	5 min 4 sec	At 5 min 4 sec, after having tried different trial-and-error attempts, they return to the analysis of each cube individually.
Phase 3. Attribution to one stimulus of the significance	10 min 49 sec	At this point, the child has attributed significance to the stimulus corresponding to the switch's visual affordance by understanding the technological affordance associated with the switch. They have internalized the meaning of one of

Phase	Time	Observed Behaviour (Video analysis)
of an auxiliary motive		the features of the power cube and are able to activate and deactivate the power voluntarily. From this moment on, they have assigned a partial meaning that advances them through her problem-solving process (a germ cell).
Phase 4a. Real conflict of stimuli	11 min 05 sec	The power cube as a stimulus is transformed from a “simple cube” to a “power cube with a switch” when they understand that the switch allows them to power the assembled cubes. Phase 4a seems to be a critical moment in the formation of voluntary action. This is when “the real or actual conflict” of stimuli takes place (Vygotsky, 1997). The voluntary action of the child is now rendered possible by having given meaning to the power cube and being able to activate it when they decide to.
Phase 4b. Closure of a conditioned connection between an external stimulus and the decided reaction	11 min 20 sec	The child expands their knowledge, creating a new configuration (Figure 7) by mobilizing the germ cell (switch of the energy cube. They have expanded their knowledge to solve the problem and developed the meaning of the activity. Although the conceptualization can be considered by the teacher as “naive” (not the same conceptualization as in the curriculum), the closure of the connection allows them to engage in artifact configuration that will shape the solution into an activity goal. The role of the teacher after this playful activity is to discuss the “naive” knowledge developed through the interaction and help connect it to domain-recognized concepts in the curriculum.
Apparatus 2	11 min 37 sec	The child effectively solves the task and is conscious of the achievement of a valid outcome for the problem situation.

The phases of decision-forming are also non-linear in the adult, with a prevalence of phases 1, 2, and 3 initially and finishing by phase 4. The switch in the conflict of stimuli is the same as observed in the child’s problem-solving, yet the adult also encountered a conflict in spatial structure which was solved by configuring the cubes horizontally, which is a more stable configuration.

Table 2

Analysis of the Adult Decision-Forming Apparatus

Phase	Time	Observed Behaviour (Video analysis)
Phase 1. Conflict of stimuli	0 sec	The adult listens to the instructions.
	22 sec	The adult evaluates the situation without touching the material for some seconds.
	26 sec	The adult explores the cubes and observes the differences among them.
Phase 3. Attribution to one stimulus of the significance of an auxiliary motive	44 sec	The adult conceptualizes the first germ cell by noticing the magnetic feature and starts to assemble the cubes one after another in a vertical way. They build a tower of cubes.
	55 sec	The adult tests the tower, trying to see if the tower moves.
Phase 1. Conflict of stimuli	1 min 5 sec	After failing the trial, they go back to the instructions. They show agency in terms of resource seeking. For this goal, they click on the system allowing them to listen to the instruction again.
	1 min 13 sec	The adult tries to build the cubes as a tower (Figure 8). Although the adult tries the tower configuration, they need to understand the cubes individually. After listening to the instructions, they try to test the tower again. They attempt to make the tower move, but there is a conflict of stimuli due to the need to separate the cubes to better understand them individually.
	1 min 23 sec	They decide to disassemble the cubes and start assembling them into a tower, which moves but also constantly falls. They persist with the idea of creating a tower despite multiple iterations where the tower falls apart.

Phase	Time	Observed Behaviour (Video analysis)
Phase 1. Conflict of stimuli	2 min 31 sec	After multiple failures of the same incorrect configuration (a tower structure which falls when the power is activated), the adult goes back to the instructions. They show agency in terms of resource seeking by clicking on the system which allows them to listen to the instructions to solve the conflict of stimuli. The spatial representation of the solution as a tower is a persistent idea (germ cell) which is inadequate to solve the problem. They are not able to inhibit this idea, which iterates the conflict of stimuli.
Phase 2. Conflict of motives	2 min 56 sec	After listening to the instructions, they try to test the tower figure again and again. They develop the same incorrect solution several times. They are stuck on the conflict of motives, so in between making the figure (built as a tower) and understanding how the cubes could assemble to overcome the problem encountered from the tower structure, which either falls or stops the movement.
Phase 3. Attribution to one stimulus of the significance of an auxiliary motive	6 min 40 sec	The adult realizes that the tower is not a stable structure after having experienced it more than ten times.
Phase 4a. Real conflict of stimuli	6 min 41 sec	The adult builds a horizontal figure (Figure 9). They compare the efficiency of the position of the cubes by building a horizontal figure instead of a vertical one (tower).
Phase 4b. Closure of a conditioned connection between an external stimulus and the decided reaction	6 min 41 sec	After comparing the position of the cubes, they decide to change the previous figure (vertical configuration) into a more stable one (horizontal configuration). They started by attributing the spatial configuration to a characteristic of stability, then went on to a more functional one.
Apparatus 2	6 min 44 sec	They succeed at the task with a horizontal configuration.

Figure 8

The Adult Tries to Build the Cubes as a Tower

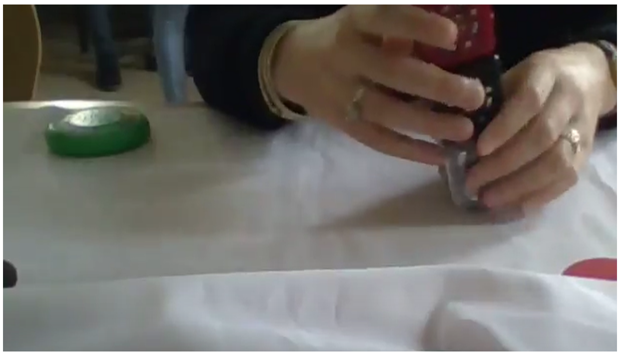
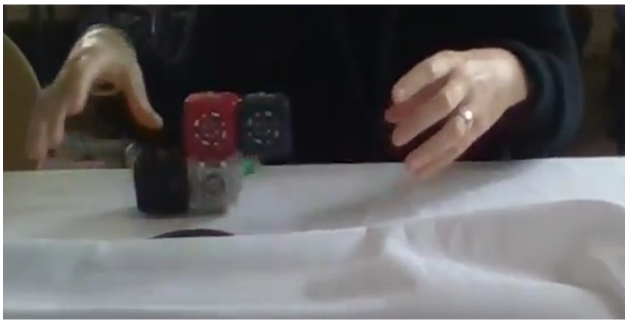


Figure 9

The Adult Builds a Horizontal Figure



Detailed Analysis of the Phases of the Decision-Forming Apparatus

Each phase is further described based on the analysis of the child's and the adult's experiments.

Phase 1. Conflict of Stimuli.

The initial situation leads to a conflict of stimuli between the instruction and the material artifacts. Even if instructions are given to the participants (creating a moving vehicle), it is not perceived as a problem if the participant internalises them through the manipulative exploration of the cubes. Therefore, there is no problem until the participant has perceived the situation as such. Then, the conflict appears between the instructions of the task (creating a moving vehicle) and the manipulation of the four cubes (at 50 seconds for the child and 44 seconds for the adult). The instructions are meaningless and decontextualized, generating a conflicting situation between the instructions and the tools if the participant has not yet explored the cubes. Instructions are not neutral and equally perceived, but they are enacted in each situation by a participant having a certain historical-cultural background.

This initial conflict of stimulus generates a certain perplexity. As described by Yew and Goh (2016), in problem-solving, Dewey (1933) observes how the learners should "make connections to this 'perplexity, confusion, or doubt' by activating their individual and collective prior knowledge and finding resources to make sense of the phenomenon" (p. 76). Dewey explains the "cognitive element of learner engagement by describing the origin of thinking as 'perplexity, confusion, or doubt' that is triggered by 'something specific which occasions and evokes it" (p. 12).

Phase 2. Conflict of Motives.

The resolution of the conflict of stimulus activates different motives (Sannino, 2015) which are necessary for a problem situation to be recognized as such. The initial tensions on the problem situation given by the instructions, as an absolute and necessary foundation related to conflicting motives, lead to cognitive dissonance. In some cases, conflicting motives are double-bind dilemmas and can be paralyzing if they are not prioritized. We can have a double-bind analysis: how to connect the faces of different cubes, but also how to activate the technological affordances on the cubes (e.g., wheels or switches). We can observe a certain paralysis at this stage of conflict of motives, especially in the child (which lasts up to 26 seconds during the initial phase). At this stage, where the participant doesn't know what to do, the tinkering interaction with the material helps to solve the conflict of motives. Being in a context of evaluation with an experimenter, these conflicting motives need to be solved because of the implicit time constraint to respect through the performance. During this period, the person doesn't know how the participant will go ahead with the task.

The child is engaged in the task but is at first paralyzed in front of the material after listening to the instructions (at second 16). After the initial paralyzing, they need the instructions to be repeated twice, then do not engage in any action before second 48. Contrarily, the adult engages rapidly in the manipulation of the tools. They are only initially paralyzed four seconds before starting the interaction. The analysis of the three persons engaged in the triangulation of data analysis has permitted the identification of momentary paralysis expressed in the form of conflict of stimuli. The time taken is not only a pause but an observable conflict of stimuli which needs to be overcome.

Phase 3. Attribution to One Stimulus of the Significance of an Auxiliary Motive.

After analyzing the characteristics of the cubes and their respective faces, the participant can try to invoke a cognitive strategy invested with meaning and engage in building a second stimulus. By exploring the cubes, the participant can find the cubes' technological affordances, such as the switch button or the wheels. This discovery generates a second stimulus for solving the task. For example, when the participant sees the wheel (stimulus), the participant can create meaning (something to move the vehicle), and then can try to verify the significance, e.g., by touching the wheels or putting the wheel on the table to test if they move as expected. In this case, the child gives an auxiliary motive to the wheels and is required to overcome this misconception to update the meaning given to the wheels.

Phase 4a. Real Conflict of Stimulus is Described as Conflicting Different Receptors on the Brain.

> A struggle is always going on in the body between different receptors for a common motor field … As Sherrington explains it, any consummated reaction, any victorious reflex, has won out only after a struggle, only after a conflict at a point of collision. Behavior, then, is a system of 'victorious' reactions. … All behavior is an unabating struggle, which does not subside even for a minute. (Vygotsky, 1925/1979, p. 15-16)

Vygotsky's description of conflicting perception stimuli is also observed in the field of neuroscience (Passamonti et al., 2009). In the CreaCube task, having four different cubes leads to an important number of conflicts of stimuli, including the cubes' position, colours, and different affordances. The subject needs to solve these different conflicts of stimuli to focus on one of them to explore it.

The CreaCube task avoids scaffolding the stimuli by giving the participant a complex set up of unknown robotic material. In this context, the complexity is more authentic than in tasks in which the stimuli are organized sequentially.

Phase 4b. Closure of a Conditioned Connection Between an External Stimulus and the Decided Reaction.

Participants should decide to focus on a certain stimulus. The case studies lead us to observe the focus of the child on the wheels and the switch. The focus of stimuli in the adult is initially on the magnetic properties of the cubes and then on a vertical configuration. They require several failures with this configuration before trying a new horizontal structure that will ensure the stability of the artifact.

To solve the task, the participant engages in a series of decisions regarding the arrangement of the apparatus to grasp the different salient stimuli provided by the proposed material. Through these different loops, the participant advances in the problem-solving task by activating DS in a series.

Double Stimulation: A Meaningful Approach for Understanding Creative Problem-Solving

The principle of double stimulation can be observed through a creative problem-solving task that engages the manipulation of tangible robotic cubes. The first stimulus is the problem situation, and the second stimulus emerges through the interiorization of the manipulative experience of the material. When the subject observes the existence of wheels, they are stimulated to think about the possibility of using or activating the wheels to move the vehicle. They can overcome a crucial tension and develop a new understanding of the problem.

Through the continuous exploration of the technological affordances of the cubes, the participant engages in further third (e.g., finding the magnetic capability of the cubes), fourth (e.g., finding the switch button), and more stimuli (e.g., understanding the interaction according to the cube positions) which help the participant reduce the problem space and get closer to one of the possible successful configurations that will complete the task.

Discussion

This study is situated in the continuation of Sannino and Laitinen's (2015) approach to the analysis of decision-forming apparatus, however, in this study the nature of the object manipulated in the CreaCube problem-solving task is materialistic. The study could reveal fruitful methodological research perspectives but also support teachers' capacity for understanding problem-solving tasks in any formal learning environment. This study provides new perspectives for understanding the difficulties learners can encounter when they face a complex problem-solving task. The conflict of stimuli in the CreaCube is observable because of the tangibility of the artifact, which is also a source of conflict of motives. In this task, the modular robotic cubes are simultaneously the tool and the object. The dialectical approach to the cubes is the object to be shaped into a certain configuration as well as being the instrument to be built into a movable vehicle. A rapid and tangible interaction of the first and second stimulus across the problem-solving process is developed when the participant manipulates the object/tool. Manipulable VCPOs (Ness & Farenga, 2016) engage the participant in the rapid and concrete activity of problem-solving that is observable through the building process of the participant. Affordances of interactive VCPOs create new opportunities for generating conflict of stimuli. These affordances are actualised in their meaning for the subject through interactive manipulation. Interactivity of robotic tools provides powerful *objects-to-think-with* (Papert, 1980) and contributes to the generation of second stimuli. What is initially perceived as a "simple cube" is transformed at a certain moment into a "power cube with a switch" the moment the child understands the switch allows them to give power to the assembled cubes. Affordances are updated at the moment the conflict of stimuli is solved. There is a clear link between affordances and DS in the problem-solving process with interactive tools. This approach to the micro genesis of the activity can be also related to the prior work of Rabardel (1995), in the instrumental genesis which operates between the participant's perception of the potential of the material and the construction of knowledge using the artifacts.

CreaCube is an ill-defined robotic problem-solving task provoking a cognitive dissonance by using DS and through which we can document conflict of stimuli and conflict of motives, both being important in engaging the subject into volitional action by giving new meaning to the task and by resolving the problem in a creative way. In creative problem-solving, as opposed to algorithmic problem-solving (Norqvist et al., 2019), current knowledge cannot be used by the participant to solve a task. The situation necessarily requires being creative, engaging in an interactive way to explore the tools, generating additional stimuli that solve the conflict of stimuli, and then overcoming the conflict of motives. As Ilyenkov (2007) stresses, through the *materialist dialectics* perspective, the participant engages in exploring unusual methods of operations. According to Ilyenkov, we should engage learners in "formulating contradictions and then find its real resolution through the concrete examination of the thing, the reality, and not by means of formal verbal manipulations that fudge contradictions instead of resolving them" (p. 21). This process that allows the generation of *germ cells* (Engeström & Sannino, 2010) is key in the decision-forming apparatus to solve the task successfully.

A short but complex task, such as CreaCube, challenges usual problem-solving methods due to the cognitive dissonance generated at the start of the task. In this study, the participant is required to engage creatively in generating stimulus by configuring the four cubes in different ways and to arrange these cubes, with important differences in terms of functional features, in a way that allows them to move autonomously, representing a "gulf of execution" (Norman, 1986) in the dissonance observed between the given tools (four cubes) and the goal of the task. The gulf of execution is considered in relation to the initial system of activity and the object which will require a reconfiguration of the activity system. Through the different interactions, the participant should build a bridge of understanding by actualising their understanding of the object affordances. This requires generating conflict of stimuli (phase 1 of decision-forming apparatus) through interaction, solving conflict of motives (phase 2), converting stimuli to auxiliary motives (phase 3), and then starting to engage in the closure of a conditioned external connection and an unmediated stimulus to decide to react (phase 4a), to finally forming the second apparatus to generate a creative solution to the ill-defined problem (phase 4b). The consideration of problem-solving using educational robotics engages a materialistic dialectic in problem-solving through the configuration of the artefacts mediating the activity. The materiality of educational robotic tools engaged in the task requires a wider range of studies to characterize the activity within its complexity. The enlarged way of considering materialist dialectic is one of the research contributions of this study on solving as a dynamic process consisting of different cycles of decision-forming.

Conflicts of motives are essential components of the principle of DS (Hopwood & Gottschalk, 2017) however we lack empirical evidence based only on these two cases, in which only one conflict of motives was observed in the adult activity. Further studies would be required to interview the subject after the activity and identify the different motives and their role in the decision-forming process. More instances of conflict of stimuli than conflict of motives were observed in this interactive tangible task. The dynamic relationship of the resolution of conflicts of stimuli can be observed in the CreaCube task through the materiality of the artifact which allows us to observe the focus of the participants, through the way the stimuli are understood but also through the misconceptions that require resolution to solve the task.

Even though the case studies are happening in a very short timeframe, the principles and features of the model of DS are coherent in a micro genetic analysis like the one of the CreaCube problem-solving task. The temporality of the problem-solving task permits one to focus on the DS process which allows one to observe behavioural gestures and artifact configurations to understand the decision-forming process. Within the interactions developed by the subject with the educational robotic tools, there are different cycles of decision making in which the concept formation allows advancing towards the activity's object.

Our study enriches the understanding of the genesis of the volitional act at the micro genetic level. Through this study, we have observed the non-linear process of the decision-forming apparatus (Sannino & Laitinen, 2015), which requires consideration of the micro genetic level in relation to conflict of stimuli, conflict of motives, and the evolution of the artifact which materializes the process of tangible problem-solving with interactive modular robots.

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Investigating Characteristics of Learning Environments During the COVID-19 Pandemic: A Systematic Review

Enquêtes caractéristiques des environnements d'apprentissage pendant la pandémie de COVID-19 : Une revue systématique

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Abstract

Dramatic change in learning environments during the COVID-19 pandemic highlighted the significance of virtual learning and led to more interactive learning environments. Quick adoption of online and social interactive learning in many universities around the world raised challenges and emphasized the importance of investigating different learning environments. This paper investigates the accelerated transition in education from traditional learning environments through online learning environments to social innovative learning environments, and the latest trends of this change. The stages of transition were divided into three parts: before, during, and after the COVID-19 pandemic, which was the reason for this accelerated change. Features and characteristics of each stage of transition were analyzed and discussed, based on the following factors: edu-space and classrooms, the learning and teaching process, curricular choices, information and communication technology applications, students' and educators' perceptions, edu-approaches, and knowledge transformation. A systematic review approach was used to investigate learning environments based on the literature reviews of previous publications. Analysis of these features revealed the main characteristics and differences in each stage. New trends in online learning environments and social innovative learning environments were identified including cloud platforms, massive open online courses, digital learning management systems, open educational resources, open educational practices, m-learning, and social network applications. Finally, this study makes two recommendations: 1) the adoption of online learning environments and social innovative learning environment applications to continue the e-learning process during the pandemic, and 2) the enhanced usage of online learning environments and social innovative learning environment applications in the future by educational institutions and governments.

Keywords: traditional learning environment; online learning environment; social learning environment; Tech-Edu-Trends; COVID-19

Résumé

Le changement majeur des environnements d'apprentissage pendant la pandémie de COVID-19 a mis en évidence l'importance de l'apprentissage virtuel et a conduit à des environnements d'apprentissage plus interactifs. L'adoption rapide de l'apprentissage interactif en ligne et social dans de nombreuses universités du monde entier a soulevé des défis et souligné l'importance d'étudier différents environnements d'apprentissage. Cet article étudie la transition accélérée dans l'éducation, des environnements d'apprentissage traditionnels aux environnements d'apprentissage sociaux et innovants en passant par les environnements d'apprentissage en ligne, ainsi que les dernières tendances de ce changement. Les étapes de la transition ont été divisées en trois parties : avant, pendant et après la pandémie de COVID-19, qui a été la raison de ce changement accéléré. Les caractéristiques de chaque étape de la transition ont été analysées et discutées, en fonction des facteurs suivants : l'espace éducatif et les salles de classe, le processus d'apprentissage et d'enseignement, les choix curriculaires, les applications des technologies de l'information et de la communication, les perceptions des étudiants et des éducateurs, les approches éducatives et la transformation des connaissances. Une approche de revue systématique a été utilisée pour étudier les environnements d'apprentissage en se basant sur les revues de littérature des publications précédentes. L'analyse de ces caractéristiques a révélé les principales caractéristiques et différences de chaque étape. Les nouvelles tendances des environnements d'apprentissage en ligne et des environnements d'apprentissage sociaux et innovants, notamment les plateformes en nuage, les cours en ligne ouverts et massifs (MOOCs), les systèmes de gestion de l'apprentissage numérique, les ressources éducatives ouvertes, les pratiques éducatives ouvertes, le m-learning et les applications de réseaux sociaux, ont été identifiées dans le cadre de cette étude. Enfin, cette étude formule deux recommandations : l'adoption d'environnements d'apprentissage en ligne et d'applications d'environnements d'apprentissage social et innovant pour poursuivre le processus d'apprentissage en ligne pendant la pandémie, et l'utilisation accrue des environnements d'apprentissage en ligne et des applications d'environnements d'apprentissage social et innovant à l'avenir par les établissements d'enseignement et les gouvernements.

Mots clés : environnement d'apprentissage traditionnel ; environnement d'apprentissage en ligne; environnement d'apprentissage social ; tendances technologiques éducatives ; COVID-19

Introduction

Early in 2020, the COVID-19 pandemic caused serious problems in education by disrupting traditional learning and closing most schools around the world, resulting in cancelled examinations, academic seminars, and workshops as well as disruptions in distance learning. This impact raised many questions about the challenges, opportunities, and solutions of educational system problems. In addition, the sudden transition from traditional learning to online learning opened other doors of discussion for scholars, researchers, and decision-makers about the future of education. Traditional learning spaces in a brick-and-mortar building (Weller, 2007) were changed to online learning spaces by adopting information and communication technology (ICT) and availability of Internet access (Al-Ansi et al., 2019). Because of the sudden change, learning environments were transformed to interactive social learning environments. These changes are significant as the future of education depends on the educational institutions' ability to adopt ICT and the new implications following the pandemic.

Dramatic changes in learning environments during COVID-19 have affected students, teachers, families, and policy-makers in education. Also, rapid technology development has helped transition the world to distance learning by the possibility of accessing the high volume of information online and the various approaches of receiving such information (Finger et al., 2007). Studies have highlighted the different results from learning in different environments, including traditional, online, blended, and distance learning. Between 1996 and 2008, a report by the United States Edu-Department identified 50 independent factors in traditional and online learning instruction (Means et al., 2009). This report asserts that students who participate in online or blended classes are more effective than those who have face-to-face traditional learning. Another study by Means et al. (2013) found that "Distance learning is more effective than traditional learning or face-to-face learning and learning in blended environments is more effective than learning in person" (p. 35). Studies by Shachar and Neumann (2010) and Wu (2015) suggest that students who take online courses have better grades than students who take traditional courses.

Predicting education's future is fraught with challenges due to the quick transition to and unsuccessful use of online learning; using technologies and e-learning systems (Almaiah & Al Mulhem, 2019), lack of technical support to facilitate various activities (Eltahir, 2019), lack of awareness and interest from the students to do more and inconsistent e-learning readiness (Al-Araibi et al., 2018), lack of security and privacy (Almaiah & Alyoussef, 2019), and other problems related to the lack of ICT infrastructure (Almaiah & Al Mulhem, 2019). However, many opportunities have been created to implement new methods and practices in the online and social learning environments, including new trends in learning such as cloud platforms, massive open online courses (MOOCs), m-learning, digital learning management system (LMS), open education resources (OER), open educational practices (OEP), and social networking applications.

Usage of e-materials during online learning is significant to conduct virtual learning (Almaiah & Al Mulhem, 2018). Acceptance of online learning during the pandemic, adoption of successful experiences, and awareness of consequences were the main factors facing students and lecturers in higher education (Almaiah & Al-Khasawneh, 2020). In addition, new technological approaches have been emerging to integrate learning and teaching through LMS such as m-learning and cloud computing (Almaiah & Al-Khasawneh, 2020), as well as a focus on the adoption of successful models (Alamri et al., 2020b) and learning from previous experiences using e-learning systems as part of traditional learning. Based on previous literature, the main objectives of this study are as follows:

- Reviewing features and characteristics of learning environments (traditional, online, and social innovative learning environments) to understand the changes regarding the transition before and during COVID-19.
- Exploring new trends in education post COVID-19 to gain best practices and improve the learning/teaching process.

Literature Review

Since the beginning of the COVID-19 pandemic, traditional learning environments have been replaced by online and interactive learning environments. During this change, many challenges and obstacles have needed overcoming (Garad et al., 2021); researchers have been exploring and investigating the best approaches and practices to continue the learning process online. During the pandemic, many studies were conducted to keep pace with such dramatic change. Social media (Alamri et al., 2020a), cloud computing (Almaiah & Al-Khasawneh, 2020), m-learning (Almaiah & Al Mulhem, 2019), augmented reality, and virtual reality were included as part of these studies to help students and lecturers continue learning and teaching. Table 1 shows recent studies in using e-learning systems, social media applications, learning platforms (Alraimi et al., 2015), and new e-learning models (Al-Ansi, 2017). In addition, some of these studies investigated other factors such as the challenges of implementing effective e-learning (Almaiah & Al-Khasawneh, 2020), anxiousness of students and lecturers during online learning (Al-Ansi, 2021), assessments of classrooms, benefits of using social media (Al-Ansi et al., 2021), and the role of ICT in e-learning. New trends have been emerging in the integration of e-learning and using ICT in education such as MOOCs, digital LMS, OER-OEP, m-learning, and social network applications (Almaiah & Alismaiel, 2019). These technologies have played an important role in conducting online learning. The main results of some of the important studies are summarized in Table 1 including areas of studies, methods and analysis, and the contribution of each study.

Table 1

Recent Research in e-Learning Environments

Subject	Methods/ Analysis	Main Outcomes
Critical challenge influencing e-learning during COVID-19 (Almaiah et al., 2020)	Interview method using thematic analysis through NVivo software	Highlighting many key features for policymakers, designers, developers, and researchers to adopt/develop e-learning systems effectively.
Task technology fit (TTF) in social networking applications (Alamri et al., 2020a)	Surveys: structural equation modeling (SEM)	Role of TTF has positive impact on the sustainability of education and reflected students' satisfaction.
Unified Theory of Acceptance and Use Technology (UTAUT) model of mobile learning and its acceptance in higher education. (Almaiah et al., 2019)	Online questionnaire/ SEM method for analysis.	Students' acceptance of m-learning is motivated by perceived information quality, compatibility, trust, and awareness.

Subject	Methods/ Analysis	Main Outcomes
E-learning infrastructure and cognitive competence during COVID-19 (Garad et al., 2021)	Quantitative approach, descriptive statistical analysis	There is significant positive impact of e-learning infrastructure and cognitive competence in conducting online learning during COVID-19.
Empirical study in using mobile phones in e-learning systems. (Almaiah & Alismaiel, 2019)	Quantitative approach-questionnaires/ regression analysis	Quality factors including System-Quality, Information-Quality and Service-Quality have a positive impact on mobile usage and students' satisfaction.
Delphi technique of using success factors of e-learning implementation. (Almaiah & Al Mulhem, 2018)	Investigation/Delphi technique	Eleven critical factors grouped as quality, technology options, top management support, and e-learning awareness are highlighted.
A model of social media in sustainability of higher education. (Alamri et al., 2020b)	Constructivism theory and Technology Acceptance Model (TAM), quantitative method, survey, SEM	Results show significant relationships among usage of social media applications and interactions, collaboration, and perceived ease of use.
Usage of mobile Information System in the University of Jordan. (Almaiah, 2018)	Questionnaire, SEM	Trust, perceived ease of use, perceived security, and perceived usefulness are the main factors for Management Information System acceptance.
Malay Language Mobile Learning System (MLMLS) using Near Field Communication (NFC) technology (Shawai & Almaiah, 2018)	Mobile Application Development Lifecycle (MADLC) model	The MADLC model was utilized to safeguard effective Mobile Language framework conveyance.
Adoption of mobile cloud computing in campuses (Almaiah & Al-Khasawneh, 2020)	Quantitative approach, integrated model	Quality of service, perceived usefulness, perceived ease of use relative advantage and trust are the main determinants of mobile cloud computing.

Methodology

A systematic approach was appropriate for conducting this study. The process of investigation three learning environments was conducted by analyzing 10 factors for each learning environment: 1) educational space, 2) classrooms, 3) learning process, 4) teaching process, 5) curriculum, 6) technology use, 7) educational approaches, 8) knowledge transformation, 9) student role, and 10) teacher role. These factors were chosen based on the pervious literature reviews and works related to each environment. In addition, the latest trends in e-learning during the pandemic were investigated. A systematic approach is helpful to explore and identify relevant research in addition to collecting and analyzing data of previous studies (Liberati et. al., 2009) and depends on reviewing previous studies for three different learning environments. Furthermore, a systematic review is designed to answer specific questions (Dewey & Drahota, 2016). The literature included in this study is introduced in three stages: before the pandemic (traditional learning), during the pandemic (online learning), and after the pandemic (social innovative learning).

Research Questions

To conduct a systematic review, these two questions were designed:

1. What are the characteristics and features of the three learning environments, i.e., traditional learning environment, online learning environment, and social innovative learning environment?
2. What are the latest trends in education environment during and post COVID-19?

Data Collection Approach

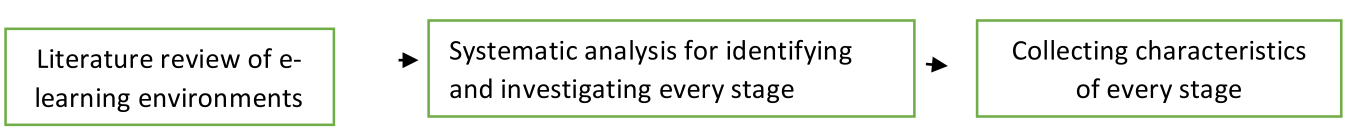
The process of collecting data depends on two approaches. First, recent studies in the field of e-learning, m-learning, cloud computing in education, and ICT in education were the keywords used for the literature-based research. Second, to investigate the main characteristics and features of each stage, many recent and older studies were included which were based on the nature of factors in each learning environment stage. For the first part of the process, regarding the data about the phenomena of full online learning due to the pandemic, all research was completed in the last two years, which correlated to the beginning of pandemic, and published in Scopus or Web of Science (Table 1). For the second part, the researcher used Google Scholar in addition to Scopus and Web of Science to include more information about the 10 factors being researched and their characteristics.

Procedures of Systematic Approach

The research procedure shown in Figure 1 presents the different steps used in this methodology. Stage one included the literature review for each learning stage (traditional, online, and social innovative environments). Stage two introduced the different factors of each learning environment and its characteristics, using a systematic approach to identify and classify each learning environment. Stage three was about gathering characteristics and features of learning environments as presented in Table 1.

Figure 1

Methodological Framework (Stages of Investigation)



Process of Investigating Learning Environment

Many different steps were taken to start the investigation of learning environments by following the systematic approach as follows:

1. The questions of research were determined, which included the main objectives for conducting this research about learning environments and the latest trends in e-learning.
2. Preliminary research was conducted to search the features and characteristics of each stage. Then, the researcher investigated every stage compared to each other as a conclusion of the study. In addition, interactive and social learning are new trends during COVID-19, where there are limited studies that have investigated these approaches.
3. Inclusion and exclusion criteria were determined: for the first part (including the phenomena and problem) only research related to COVID-19 and for the second part (characteristics and features) much broader research was included.
4. In terms of searching the database, all papers included for the first part were selected from high quality journals indexed in Scopus or the Web of Science, while in the second part, data was collected from both resources as well as Google Scholar.
5. The main factors of each stage were used as keywords to search for related papers. Four titles were designed for each stage including (Educational Space and Classrooms, Learning/Teaching Process, Curriculum and Educational Approaches, and Knowledge Transformation). In addition, one more title was chosen for the latest trends.
6. Data was collected for each title and subtitle separately and each part was investigated by the researcher to ensure the validity of the data and correlation between them.
7. Finally, each learning environments' characteristics and features were summarized (Table 2).

Stages of Transitions in Learning Environments

At the beginning of the new millennium, many educational institutions adopted technology in the learning process using digital devices in the classroom, Internet access, ICT-based learning, blended learning, and distance learning. This section investigates the transition from the traditional learning environment (TLE) before COVID-19 through online learning environments (OLE) during the pandemic to social innovative learning environment (SILE) after the pandemic.

Traditional Learning Environments

This first stage is the traditional learning environment before the COVID-19 pandemic. Characteristics of this stage include physical classrooms where students and teachers attend classes at campus or school, teacher-based learning where the teacher is the transmitter of knowledge, many educational materials and books which are printed, the use of the transition of knowledge approach, and many ICT tools which are part of classrooms.

Educational Space and Classrooms

Traditionally, this type of learning is based on a face-to-face approach in a physical environment, which is also known as brick-and-mortar classes (Weller, 2007). Students who learn in these places adopt the concept of a broadcast model of learning (Long & Ehrann, 2005). Traditional learning creates what is called sensory memories, also referred to as the "ability of emotional responses" that work to influence their cognitive and behaviour (Graetz, 2006). Some researchers believe the concept of traditional classes limits the student and teacher activities and interactions (Mulcahy et. al., 2015) and hamper the ability of teachers to easily activate different approaches such as student-centred and ICT-based learning (Dovey & Fisher, 2014). Traditional or conventional classrooms are ideal for teacher-based learning methods that prefer linear and standardized instruction (Dumont & Istance, 2010). Physical learning environment designs and features also impact the students' experience and orientation towards learning (Wilson & Cotgrave, 2016). Some of these features include learning space, lecture hall, teaching rooms, access to library, toilets and open social areas, room layout, colors and furniture, and up-to-date technology. Understanding the students' needs is critical to developing a suitable learning space (Kollar, 2014) that supports learning strategies and provides a suitable environment for students to manage the space for their own work productivity (Shouder et al., 2014).

Learning/Teaching Process

In traditional learning environments, teachers are the transmitters of knowledge, the controllers of the class, and the responsible parties for all activities; the students are the receivers of instruction. Traditional learning focuses on rote learning and memorization in addition to examination as the end of the educational process. Teacher-centred learning communicates and facilitates learning approaches and materials for students where teachers have a primary role (Mascolo, 2009). This approach depends on the teacher and leads to an exam-centred approach to save time and focus on the test content (Grant & Hill, 2006). Paper and pencil exams, scripted curriculum, and face-to-face teaching in the traditional learning approach makes students increasingly bored and unmotivated, and the teacher more stressed about teaching techniques (Fullan & Langworthy, 2013). Some researchers prefer teacher-centred learning when the teachers are knowledgeable in content and can apply motivational techniques to their teaching approach (Espenshade & Radford, 2009). These teachers spend more time explaining the content and discussing related issues by using black/whiteboards and projectors while students take notes and ask questions (Peyton et al., 2010).

Curriculum

Traditional learning environments depend on teacher-centred learning, textbook instruction, blackboards, and a pen and paper approach. In this stage, even though many non-traditional educational methods have been implemented such as team-based learning, problem-based learning (PBL), content-based learning, flipped classrooms, and self-directed learning, the curriculum plays the main role and textbooks are the basis of the learning process (Choi et al., 2014; Nishigawa et al., 2017). In addition to using textbooks, visualizations and 3D pictures, presentations, and videos also play a significant role.

Educational Approaches and Knowledge Transformation

Traditional learning depends on a transitional approach where information and knowledge are transmitted from educators to learners. The teacher's beliefs and role determine the type of educational approach used and knowledge selected to be delivered to students (Domović et al., 2017; Rapoport et al., 2016). Several studies confirmed the importance of the teacher role in teaching and learning in traditional environments (James, 2013; Domović et al., 2017; Rapoport et al., 2016). Although many educational institutions use traditional learning approaches for delivering knowledge and practices, during the last two decades, many ICT and technologies have been brought to classrooms. This interaction between students and technology has facilitated students' future careers and improved their skills and competences. Future jobs depend on the ability of graduates to interact with ICT and possess general skills such as the creation and sharing of collaborative knowledge as well as metacognitive skills (Kozma, 2005). Transitional learning outcomes are related to cognition, projective, application, synthesis, group strengthening, and self-direction (James, 2013).

Online Learning Environments

This stage introduces the approaches and techniques used in OLE during the COVID-19 pandemic. The main features of this stage include learning from home, online classes, student-based learning, an interaction environment between students and teacher, e-learning books and materials, and creation of knowledge approaches.

Educational Space and Classrooms

In online learning, students, educators, and administrative staff no longer need to go to the school building. The physical learning environment is the home or any place students can learn. The LMS is controlled by educational institutions and educators, while students have specific space to do their activities online (Väljataga et al., 2011). Socialization and interaction have changed from the campus to interactive platforms and social media. In fact, many students prefer to use social media where they can interact more with their classmates and teachers. Previous studies show that students and teachers spend significant time on social media interacting and participating in different activities (Junco, 2012; Garad et al., 2021). In addition to social network and online applications, the educational space at home facilitates gathering the family and community around.

Learning/Teaching Process

During COVID-19, online learning has become the only approach to continue learning. Many educational institutions have offered online learning and teaching as extra activities or limited use for those unable to attend in-person classes. The requirement to teach and learn online during the pandemic enabled students and teachers to improve their skills and transform to online learning and teaching, however, many are struggling to learn different skills to adopt this approach even though online learning has become compulsory, since the closure of schools/universities. Student-based learning is the main feature of the online learning process, which includes both Problem-Based Learning (PBL) and Project-Based Learning (PjBL). These two approaches are similar (Hung, 2011) but each has unique features. Problem-based learning introduces the problem for students to solve, whereas PjBL introduces the artifact to be achieved. Students in PBL produce conclusions of problem-solving, while students in PjBL end with a product. In both approaches, the teacher is the facilitator of the learning process but not the transmitter of knowledge. The online learning and teaching process also includes many different approaches like using an LMS, virtual classroom, MOOC, and educational gaming applications. These tools and approaches enable virtual interaction to be more flexible than physical interaction by including student to student, student to teacher, student to content, teacher to teacher, teacher to content, and content to content interaction (Zornić & Hasanović, 2011).

Curriculum

In OLE, the use of printed textbooks is rare as students prefer e-books, presentations, and audio and video content. In traditional learning, e-learning materials remain unchanged as all materials simply become e-learning materials. Although interactive and social platforms have been adopted as part of the e-learning process, this progress is limited due to the difficulties related to full e-learning, lack of infrastructure, and lack of student and teacher competence in using the interactive platforms. Regardless of such challenges, the curricula are not typically separated into individual subjects, which allows students to develop skills across the curriculum, and to learn and apply their knowledge wherever they need it (Papert, 2001).

Educational Approaches and Knowledge Transformation

In online learning environments, interactive learning is the approach to learning where students and teachers use online applications and platforms to communicate and interact with each other. Knowledge is created through this interaction, and the participation of students and teachers is in opposition to traditional learning where teachers are the transmitters of knowledge. Sharing and creating e-learning materials, videos, presentations, and e-books enhance the learning, allow for the sharing of experiences, and improve teaching performance (Lee & Wu, 2006; So et al., 2008; Yung et al., 2007). Technology is the base in online learning, and the tool for creating knowledge. Teaching is conducted by constructivism, Web 2.0 tools, and interactive platforms. Teachers are responsible for planning classes, determining the approaches and applications of learning, and facilitating an integrated learning technology, while students are responsible for building and demonstrating knowledge as well as collaborating with their peers to create knowledge.

Social Innovative Learning Environments

In social innovative learning environments, there are many predictable specifications after facing COVID-19 such as technology-rich spaces, interactive platforms, ICT-blended learning, community learning environments, student and teacher learning and teaching everywhere the Internet is available, social media interaction, and innovative applications of knowledge. In this stage, there is a specific selection on the use of ICT and teaching conducted through innovative and open social environments.

Educational Space and Classrooms

Social innovative learning environments are multi-social media based, technology-integrated, and attractive, including numerous practices in education (OECD, 2015). Several studies have evidence of effective SILE as a better learning method than traditional classrooms (Dovey & Fisher, 2014; Garad & Al-Ansi, 2021; Al-Ansi & Al-Ansi, 2023). In SILE, there are no physical classrooms or learning online at home. The space of learning is anywhere having Internet access and mobile phone such as coffee shops, clubs, or open outdoor space. Moreover, social media has enriched the learning process where students and teachers can easily interact and communicate anytime and anywhere. In SILE, learning space is not restricted by physical boundaries; classrooms are transformed into social networks and groups into social media applications. Facilitating learning spaces depends on social media application features and how comfortable, affordable, reachable, and easy they are to use. Learning virtual spaces in SILE are represented as electronic emulations of the multidimensional natural world.

Learning and Teaching Process

As opposed to traditional and online learning, where traditional learning adopts teacher-centred and online learning represents student-centred approaches, learning in innovative social environments is an ICT-based method. The teaching process in SILE also depends on the interaction of the community with technology, which means not only teacher-student interaction, but family, technology, space, and community have a part in this learning environment. Teaching and learning in SILE requires different approaches, collaboration, and communication, and includes suitable knowledge and emotions (Gao et al., 2012; Greenhow & Burton, 2011; Pimmer et al., 2012; Ranieri et al., 2012). The process of learning in SILE is characterized as self-direction, self-initiation, peer- or other-influenced, unintended network effects, network support, community evaluation (rating, commentary, expertise via participation, bookmarking), and the use of other modes such as videos, pictures, ratings, and tags (Greenhow & Lewin, 2016). Social media and innovative learning approaches have enhanced the culture of the new learning environment. Learners and educators can engage and participate in digital culture, potentially benefitting from collaborative learning and developing new skills (Brenner & Smith, 2013; Ofcom, 2014). Despite learning through social media, which also enriches the skills and experience of learners and educators, many challenges must be met to understand the complexity of future learning.

Curriculum

In addition to learning e-materials, whiteboards, and interactive platforms, virtual excursions and practices are the most features of curriculum in social interactive learning environments. Learners and educators can read, edit, organize, interact, and save these learning materials anytime. Open textbooks, MOOCs, OER repositories, and open collaboration forums are available for educators and students to learn, share, and download according to their needs (Algers, 2019; UNESCO, 2015). Although many open educational materials are available online, there are some limitations and difficulties choosing materials that best suit the learners' needs including copyright, license, unfamiliarity, and quality of materials (Ozdemir & Bonk, 2017; Yang, 2020).

Educational Approaches and Knowledge Transformation

In SILE, students learn through social networks and applications. In other words, knowledge is not only transformed or created among students and teachers, but knowledge is also gained through interactive applications. As well, students are more motivated to engage in learning through open interactive environments (Nascimbeni & Burgos, 2016). Learning through social networks enables students to create new OER and OEP in any specific topic based on available resources and references.

New Trends in the Future of Education

During the COVID-19 pandemic, many new trends resulted in new learning and teaching processes. Traditional learning transformed into distance learning where policies, strategies, techniques, applications, and suggestions reshaped and restructured the culture of learning. This section investigates these trends. It is significant that many of these trends in learning have been identified in the last few years and adopted as part of traditional learning strategies. During and after COVID-19, these forms and techniques developed and became essential in distance learning infrastructure.

Cloud Platforms

The idea of a cloud or interactive platform is to facilitate the use of ICT to create a better learning environment. Cloud platforms depend on ICT applications, an LMS, interactive websites, and social media (Almaiah & Al Mulhem, 2019). They enable components of traditional learning such as textbooks, note writing, group discussion, idea sharing, and accumulated cognition in a sufficient way based on ICT, LMS, and e-learning components, in addition to more chat box and news feed ability to comment in an open course system (Septiani et al., 2017). Personal computers, laptops, tablets, and cellular phones employ built-in integrated cameras, GPS sensors, and Internet access to embed real-world environments with dynamic and context-aware interactive digital content (Chiang et al., 2014). These are the cloud platform tools where learners/educators can interact with each other. In addition, teleconferencing applications, such as Zoom, Google Meet, Facebook Groups, Microsoft Teams, and many other applications, have increased during the pandemic and have facilitated communication between learners and educators and given them the ability to interact synchronously with each other.

Digital LMS

Digital LMS helps learners and educators access the learning anytime and anywhere. After school and university closures, due to COVID-19, the concept of an LMS was the lifeline for education. An LMS is an online platform that includes learning systems, content and course management systems, portals, evaluation systems, and instructional management systems. Since students are considered digital natives (Prensky, 2002) or a social media generation, using an LMS is easier and more functional for many of them. The LMS has revolutionized the approach to learning during the last few years and LMS growth is expected to increase from USD 13.14 billion in 2020 to USD 25.7 by 2025 (Markets, 2020). Learning management systems have enabled student-teacher interaction and given them the ability to connect, communicate, share information, ideas and materials, conduct examinations, manage courses, and track students' attendance and assessment. There are many open-source cloud-based systems that introduce low-cost courses, free solutions, and maintenance, but the large systems are those installed and developed by educational institutions where the university or school owns, maintains, and secures them. Well-known LMS include Moodle, Loop, Docebo, LearnUpon, Adobe Captivate Prime, Talent, and Sap Litmos (Pappas, 2018), and include characteristics like customer support and experience, software features and innovation, economic growth, friendly use, and feedback.

Mobile Learning

M-learning refers to browsing knowledge and learning through using phones and/or mobile-device applications and is categorized under e-learning and involved in mobile computing (Behera, 2013). Regardless of limitations using the m-learning approach, mobile phones have become an important tool for learning during the pandemic and will continue to be post COVID-19. Ease of use, mobility, affordability, and access to information quickly are the main characteristics of m-learning (Almaiah & Al Mulhem, 2019). In addition, mobile devices are used as a communication tool through social media, using mobile products such as scanner, printer, video, and camera to conduct teleconferencing and join cloud platforms. M-learning expands learning and teaching beyond traditional learning in classrooms, increases flexibility, and opens opportunities for learners and educators through OLEs (Kumar Basak et al., 2018). M-learning also has a fundamental perspective of e-learning including technology mobility, learning, and learner synchronously (El-Hussein & Cronje, 2010). Many studies discuss the different features, use, and parameters of m-learning including portability, social interaction, sensitivity to the context, connectivity, and ability of customization (Kothamasu, 2010), incorporating m-learning in higher education environments by student awareness and knowledge (Hashim & Ahmad, 2012), high satisfaction of students using m-learning, m-learning being a future learning unique tool (Mao, 2014), and integrating m-learning by various software and hardware technologies to facilitate communication and interaction with multimedia applications like short messaging, gaming, examinations, and multimedia contents (Mohanna, 2015).

MOOCs

Massive open online courses include formal and informal educational online resources based on connective knowledge (Siemens & Downes, 2018) and behavioural approach (content-based) theories (Yuan & Powell, 2013). The idea of c-MOOCs introduces the connection between different parties to engage in discussions and collaboration while x-MOOCs are designed as traditional learning courses but online (Yousef et al., 2014). There are many examples of e-learning MOOCs including Khan Academy, edX, Peer-to-Peer University (P2PU), Udacity, Udemy, Alison, and Coursera. The role of educators and professionals is to prepare and produce MOOC materials and upload it online for learners, a process that requires much time. Over the last few years, millions of learners have joined MOOCs (Almaiah & Al-Khasawneh, 2020). For instance, Coursera includes thousands of online courses, professional certificates, bachelors and masters online degrees, and more than 60 million learners. Also, many critiques have discussed challenges related to MOOCs such as attrition and course dropout rates (Hew, 2016). Reasons behind dropping out of completing courses include difficulty of use, workload, no motivation in addition to inequality and fake registration (Alraimi et al., 2015).

Open Educational Resources - Open Educational Practices

Open educational resources and open educational practices are new approaches to learning; a set of learning and teaching materials that enable pedagogy and define its characteristics that are available online for public use and at no cost. Users can reuse, repurpose, adopt, and redistribute these materials anytime based on their needs (Stracke et al., 2019). OER is a content-based learning approach and offers the ability to reuse, revise, remix, redistribute, and retain these educational resources (UNESCO, 2015), while OEP is practice-based and has the potential to improve the opportunity for learners to access quality educational content, thus helping to achieve both accessible and lifelong learning (Nascimbeni & Burgos, 2019). Implementing OEPs requires reusing OERs in different ways to support students' learning and keep them active, which results in better educational outcomes. In addition, applying OEPs requires many steps such as open licensing, open learning and teaching, open collaboration and communication, available assessment, and enabling technologies (Huang et al., 2020).

Social Networking Applications

Social media networks have a significant role in modern learning and teaching approaches (Alamri et al., 2020a), whereby students and teachers can connect, communicate, interact, share knowledge, and send and receive assignments easily using cellphones and laptops (Myers et al., 2012). Popular social media applications include Facebook, Twitter, LinkedIn, Blogs, YouTube, Instagram, and Pinterest in addition to communicating applications such as WhatsApp, Telegram, Skype, Line, Imo, and Messenger (Chawinga & Zinn, 2016; Dzvapatsva et al., 2014). Social media is no longer only used for leisure but as a platform for communicating and teaching/learning (Jones, 2015). Social media also provides the opportunity for students to give feedback and for educators to identify knowledge gaps and improve the teaching methods (Menkhoff et al., 2014). In addition, whether mobile- or laptop-based, social media has many benefits such as enabling students to interact positively with contextual learning in relation to pedagogical objectives, engage in collaborative learning, and post comments and questions (Menkhoff et al., 2014; Wheeler, 2010). Despite evidence of the usefulness of social media applications in learning, there are also many critics and paradoxes that hinder the full adoption of these applications (Conole & Alevizou, 2010; Tess, 2013).

Discussion and Conclusion

This research investigated the TLE, OLE, and SILE learning environments because of the changes and dispersions of education post COVID-19. Emerging technologies and the integration of ICT enables universities to conduct online learning through LMS and virtual platforms. These results are supported by research about learning during the last two years during COVID-19 (Alamri et al., 2020a, 2020b; Garad et al., 2021). During the transformation, many challenges have been raised such as lack of experiences (Almaiah & Al-Khasawneh, 2020), lack of resources, anxiety (Al-Ansi, 2021), and difficulties using the new applications (Al-Ansi & Garad, 2021), which has led to changes in the learning environments. With the continuing impact of COVID-19, many universities depend on distance learning and ICT components.

Before the pandemic, traditional (face-to-face) learning was the most well-known and main approach adopted in universities around the world while virtual learning was conducted in some universities and exclusive for those not able to attend classes. During the pandemic, online or virtual learning became the only approach to conduct learning. Using social media and m-learning has become more effective and made e-learning more efficient (Alamri et al., 2020b; Almaiah & Al Mulhem, 2019). In future, even though it is hard to predict, the effectiveness of online learning and the attractiveness of social and interactive learning demonstrated the ability, flexibility, and reliability of both. Social learning and traditional learning features and characteristics help to understand the changes in learning practices and policies. Different characteristics distinguish each stage of learning based on factors such as educational environment, classrooms, learning and teaching process, curriculum, technology, educational approaches, ways of acquiring knowledge, and student and educator roles. All these features have changed due to transitions in the learning environment. Table 2 summarizes these changes based on learning environments.

Table 2

Summary of Changes in Different Learning Environments

Factors	TLE	OLE	SILE
Ed-environment	Campus/school	Home	Tech-rich space
Classroom	Physical classroom	Online classes	Interactive space
Learning	Teacher-centred	Student-centred	ICT-based/task-based
Teaching	Educator/lecturer	Teacher-student	Community environment
Curriculum	Printed ed-materials	E-ed-materials	Interactive platforms
Tech-space	In-classroom	At home	Everywhere
Ed-approaches	Transition-nets	Interactive nets	Social networks - SILE
Knowledge	Transformed	Created	Innovative applications
Student	Passive	Active	Creative
Teacher	Transmitter	Coach	Participant

The traditional learning environment is still the dominant approach mixed with ICT, while online and interactive social learning have become significant in the future of education. Regardless of changes during the pandemic, where education depended on online and interactive learning, education will return to traditional learning but with significant improvement in all three environments. In addition, some new trends that have been adopted and became critical in learning, such as cloud platforms, m-learning, MOOCs, digital LMS, OERs, OEPs, and social networking applications, have been demonstrated as part of this research.

Recommendations

According to an analysis of the learning environment transition stages before, during, and after COVID-19, and the new trends that appeared, recommendations should be considered to reduce the risk and mitigate the pandemic's negative effects on education.

- Improve educator and student competences and self-motivation to adopt OLE and SILE approaches, techniques, and applications, as well as increase their ability to interact through these platforms.
- Educational institutions and governments must implement new policies and regulations and assess the transition from TLE to OLE and support the change to SILE by providing integrated ICT infrastructure and financial support.
- International collaboration and community interaction has become important to share experiences, support learning environments, and provide sustainable development of learning and should continue and be enhanced. Universities and communities must consider this when planning future collaborations.
- Reshaping, redefining, and redesigning educational systems should include the learning and teaching process, curriculum, educational space and environment, and assessment approaches.
- Consider the adoption of and adaptation with ICT, cloud platforms, MOOCs, ODRs-OEPs, m-learning, and social network applications.

Implications

Theoretical Implications

The COVID-19 pandemic is ongoing at the time of this writing with no certainty over the duration and extent that the pandemic will continue to affect education systems around the globe. COVID-19 has changed the perceptions and understandings of the traditional learning process and, for the first time in history, education has been conducted completely through online learning. This event will continue to change the methods, approaches, strategies, and policies for education for the coming years. Some important criteria remain to be measured, such as the way in which social and cultural dimensions affect education patterns in the context of the current crisis. As the situation continues and the crisis is prolonged, education expectations need to be continuously revised and new theories, policies, and collaboration implemented.

Practical Implications

Education after COVID-19 will change traditional learning and therefore educational institutions need to be ready to implement new strategies and adopt ICT equipment and tech-ed approaches. During the pandemic many students have dropped out of learning and will continue to dropout of schools, based on many socioeconomic reasons. In addition, many students will not be able to pay for schools, in the case of primary education where families may have lost their jobs due to the pandemic, or for universities in case of higher education, where students themselves are working part-time and may have lost work. The financial burden of low-income students has pushed many families to send their children to work to support their family facing the pandemic. In addition, many students who live in conflict or war-affected areas, who are displaced, or who already face challenges to remain in schools have been affected more than other groups.

Social Implications

During and after the pandemic, people must still care about social distancing, where they are not allowed to directly interact with each other. This realization has led to physical separation where the relationship between students and teachers now depends on ICT tools and/or social media applications. Many students have stress and depression because they must stay home to pursue online classes while in traditional learning they could spend time at school and home.

Further Directions

For future research, the question is if education's future will remain as in the pandemic time (online or blended) or if it will return to traditional education. The role of offline systems, community engagement and international collaboration, entertainment in education, and privacy and security challenges will remain important subjects for future studies in education.

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