FOSTERING COMPUTATIONAL THINKING IN REMOTE LEARNING SETTINGS

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Abstract

As the COVID-19 pandemic continues to take its toll worldwide, school systems provide continuous instruction via remote and hybrid learning modes. In this fluid environment, the regular challenges of fostering 21st-century skills such as computational thinking, have become even more complex. To foster critical thinking the Israeli ministry of education has recently elevated its expectations from computer science instruction in elementary schools to integrate computational thinking skills. The main challenge facing the education system in this regard is the lack of teachers' knowledge in content, pedagogy, and technology for guiding large classroom levels in remote learning of computational thinking. This paper explores a creative STEM course and reports the course results.

This intervention research of a teacher-guided, cross-curricular course was conducted remotely during school hours. Over 270 upper elementary school students were selected to participate. Thirty-two learning hours were administered over the year. A group of professional teachers created the learning tasks along with the researchers. The research was conducted with a quasi-experimental method using pretests and posttests, semi-structured interviews, project evaluations, and in-class observations. Results indicate that the students improved their computational thinking skills and enhanced their science understanding. Compared to a similar study conducted before the pandemic in regular school settings, remote learning showed slightly improved results.

Students deserve engaging, relevant remote learning applications. Many argue that remote learning is needed beyond current social distancing regulations; thus, we encourage further research into methods for remote learning in education that fosters 21st-century skills such as computational thinking. Emerging from this global pandemic with a stronger public education system is an ambitious vision that can be achieved using a new paradigm of cross-curriculum courses that foster critical thinking.

Keywords: Remote learning settings, Computational thinking, STEM, Guided discovery learning.

1 INTRODUCTION

During the 21st century, humanity faces unprecedented challenges – social, economic, and environmental – driven by accelerating globalization and a faster rate of technological developments. At the same time, those forces are providing us with myriad new opportunities for human advancement. As the fight to contain COVID-19 continues, initiatives to maintain learning continuity are being tested in different contexts in real-time. Pooling resources, research, and real-time insights to invest in this generation of students is a global necessity. Currently, there is no standard template for determining whether to educate students remotely, bring them back into the classroom, or create a hybrid model that combines both [1]. In Israel, the 2021 school year has commenced with remote learning, enabling continuous instruction.

Education needs to be open and ready for changes, meaning that schools should prepare students for jobs that have not yet been created, for technologies that have not yet been invented, for solving problems that have not yet been anticipated. Education should equip learners with a sense of agency and purpose, as well as the competencies they will need to shape their own lives and contribute to the lives of others. Among these, it is fundamental for students to acquire 21st-century skills such as problem-solving as part of interdisciplinary STEM learning [2]. While the individual STEM subjects are taught separately in most curricular contexts, there is evidence to support the consideration of STEM as a single, unitary domain. Knowles and Kelley [3] argue for the unification of STEM, although they also acknowledge the challenges involved. To address them, they suggest approaching STEM through a lens of situated learning cognition, which recognizes that the context, including both physical and social elements of a learning activity, is critical to the learning process. When learning is grounded in a situated context, education is authentic and relevant, representing an experience found in actual STEM practice.

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Complex problem solving, sometimes referred to as productive struggle, is fundamental to successful STEM learning. In the United States, the National Council of Teaching Mathematics listed productive struggle as one of eight essential teaching practices. It noted that “effective mathematics teaching supports students in productive struggle as they learn mathematics” [4]. The productive struggle to advance problem-solving skills in STEM can benefit significantly from coding activities. Coding enables students to create software simulations and get immediate feedback, which opens endless opportunities for science and math learning [5], [6], [7] even in emerging technologies [8].

Science is becoming a computational endeavor. Therefore, Computational Thinking (CT), which is a set of problem-solving skills, is gradually being accepted as a requirement for the 21st century student. In 2016, Israel launched a program to teach Computer Science and Robotics as an elective course for students in grades 4 – 6. In 2020, the Ministry of Education changed the title to Computational Thinking and Robotics to reflect the goal of fostering critical thinking while teaching computer science (CS). Teachers are required to focus on four CT skills: Abstraction, Decomposition, Algorithm Design, and Pattern Recognition [9]. The main challenges facing the education system in this regard are that teachers are unfamiliar with CT, the number of qualified teachers in teaching CS is insufficient, and teachers need a different pedagogy to guide large classroom levels in remote learning. Thus, in times of social distancing, educators have an especially difficult problem.

Teaching at the most basic level follows an iterative process known as the Teaching Value Chain [1]. Starting with direct teacher instruction for students provides students an opportunity to explore content through experimentation, discussion, guided practice, and independent work. Teachers then use formative assessment of what students have learned and what they are still struggling with—information that informs the next round of instruction and exploration. However, following this process is often challenging in remote learning settings. A survey conducted by the Israeli National Authority for Measurement and Evaluation in Education [10] demonstrated these challenges: 49% of teachers reported that their home offers poor or mild conditions for distance teaching with respect to privacy and noise; 46% reported they had a poor or mild set of lesson plans and pedagogical materials appropriate for remote learning and 78% said they feel a need for additional training on conducting remote learning lessons. Some teachers have articulated difficulties with motivating students, specifically getting them to stay focused, actively participate and be accountable for their learning. For instance, some students find it hard to follow a remote lesson provided to a large group of students.

Although educators strive to create an ideal learning environment for every student, the realities of budgets, time, and talent constraints require adjustments for remote learning. A "COVID-19 Response Toolkit" for school systems created by UNESCO [1] lists several suggestions. Among them are to design systems specifically for remote and hybrid environments. Remote learning is more than just a digital version of the classroom. In addition, teachers need to feel safe and equipped to teach. School systems need to invest significant time listening to teachers' concerns and working jointly with them to create solutions. Part of that is to train teachers so that they provide remote and hybrid instruction effectively. Another suggestion is to differentiate by the level of need and capability. Educators need to understand the value of tailoring curriculums and classroom environments to the needs of different learning systems.

A recent study on remote learning found that working on solving problems connects directly to productive classrooms [4]. It is affirmed by evidence that learning is not contingent on successful completion of tasks, but on having opportunities to engage with complex tasks and to contemplate the underlying content deeply, and on being encouraged to persist through challenge [11]. Teachers noted the lack of opportunities to connect to and collaborate with peers as an obstacle to student willingness to attempt difficult tasks in a remote learning setting. Social isolation brought on by remote learning was one of the most significant challenges identified by students. A key aspect of learning through challenging tasks in classrooms is the expectation that all students will be in the "zone of confusion" together [12]. The relative isolation experienced by students during remote learning, even during synchronous virtual sessions, would undermine this shared experience. Another challenge to consider is the difficulty of accessing learning materials remotely. Teachers noted that students would tend to access concrete materials to make sense of the mathematics better when struggling with a task in a classroom. The lack of access to such materials in their home environment meant that students were less likely to be successful with their learning: Materials weren't as accessible at home as the school.

Pedagogy has an essential role in learning outcomes. In CS learning, the most popular intervention approach in research involves constructing their programs with scaffolds [13]. This approach arose from constructionism which "attaches special importance to the role of constructions in the world as a support for those in the head, thereby becoming less of a purely mentalist doctrine" [14]. Constructionism with scaffolds is one method of structured, guided discovery learning (GDL) pedagogy relevant for STEM courses [15]. This pedagogy proposes pointing the way to problem-solving by providing a guide to discovering facts, relationships, and solutions by students themselves [16]. Pure discovery learning methods, in which students have maximal freedom to explore, are less beneficial to student outcomes than GDL. Therefore, it is recommended that the students get systematic guidance focused on the learning objective [17].

The GDL principles for teachers are: form a problem for students to solve that aligns with their level of cognitive development; clearly present the problem; prepare required appliances and materials; arrange the curriculum to allow free flow of mind in learning activities; provide an opportunity for the students to collect data; and supply students with the information that is required [16]. There are several specific learning purposes with GDL: students can be actively involved in learning by inventing solutions to problems that can increase student participation in learning; students learn to find patterns in situations and extrapolate the additional information provided; students learn to formulate the strategy of questioning as they frequently ask questions to obtain information; they form effective ways of working together, sharing information, and listening to others; skills, concepts, and principles learned are better learned in meaningful discovery; the skills learned are transferrable to new activities and applied in new learning situations [18].

One form of challenging students with problems to solve while applying CT skills is by creating an agent-based model and simulation (ABMS). ABMS is the process of creating a computer software system that models a natural phenomenon. Its behavior is composed of its components' actions and their interactions with other components [19], [20], [21]. In ABMS, the components are called agents, which typically have multiple instances and can explicitly incorporate the complexity arising from individual behaviors and interactions in the real world. Creating the simulation usually requires using CT skills [22]. For a schematic view of the agents and their interaction, see Figure 1.

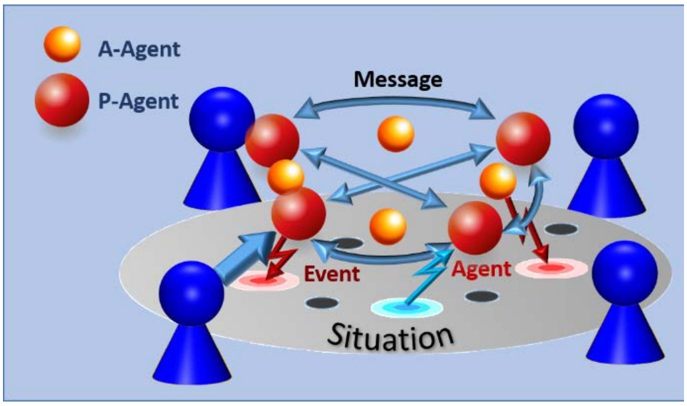

Figure 1: A schematic view of agents in ABMS

A practical process for creating ABMS is the 'Computational science process' described by the NRC framework [23]. It is an orderly repetitive five-step process that enables the creation of models and simulations for scientific inquiry, with CT being the critical thinking skills driving it. In this sense, CT is the human capability to create an automated model of a real-world phenomenon. The process starts with a real-world problem or phenomenon. Abstraction is used to simplify the complex real-world problem to a manageable idea by reducing it to essential elements and relationships. The outcome of the abstraction is the model. The model is then translated to a computational model, also known as simulation. The latter is formulated based on algorithms which are the computational steps required for the model to be automated and run on a computer. Then the simulation is used as a testbed along with variables and parameters. Experiments are carried out on the simulation using different parameters. Data is collected and analyzed, with the results being interpreted back to the real-world problem. The primary goal is to create a model and evaluate how it resembles the real world.

The rest of this paper is organized as follows: Section 2 deals with the study methodology, research design, and research process. The study results are presented in Section 3, and the Conclusions are provided in Section 4.

2 METHODOLOGY

This chapter describes the intervention research course in remote learning settings that was constructed for the study; additionally, the participants, the research questions, and the data collection instruments are presented. The course consists of a school program focusing on student's acquired computational thinking skills in a multidisciplinary STEM course. The researchers of this study, along with content and pedagogical experts in math, science, and computer science (CS), created the curriculum for the course.

2.1 Participants

The course was administered in 14 schools, with 276 students participating. Due to challenges related to the COVID-19 pandemic, such as staff, three of the schools started late, two more schools did not follow through with the course, and one school had inconsistent student attendance. Therefore, we used data obtained from 160 5^{th}- and 6th-grade students, ages 11-12, representing eight public elementary schools in Israel. The students provided parental and personal consent to participate in the research study. Approvals were obtained according to the regulations of the Chief Scientist Office of the Ministry of Education. The teachers selected students who liked learning and were well-behaved to participate in the course. It was an elective course for the students and took place at the end of the regular school hours as the last lesson of the day.

2.2 Research questions

A unique STEM course with a high emphasis on advancing students' CT skills was administered in a distant learning format using the Guided Discovery Learning pedagogy. This pedagogy combines pointing the way to problem-solving by a guide to discover facts, relationships, and solutions by students themselves. In addition, the constructionist method was used. The final course project task was to create an agent-based model and simulation based on the computational science process. Accordingly, the research questions are:

1. What are the reported outcomes of the intervention learning program on students' science learning and agent-based modeling?
2. How do young students perform in a remote learning format class as opposed to in-class settings?

2.3 Curriculum

Four learning modules were developed to study students' CT skills that actively engage students with problem-solving in 3 curricular topics: Science, Math, and Computer Science. The course duration overall was 38 hours. It comprised 22 weeks of 1 hour-a-week learning; three events, each 4 hours long; and four lectures, each 1 hour long.

Each learning module comprised tasks to work on collaboratively and had a theme which was one of four CT skills: Decomposition, Abstraction, Pattern Recognition, and Algorithm Design. Since teachers had no prior knowledge of CT, the introduction part of a module consisted of reading materials and videos to explicitly learn the CT skill at hand. In addition, a lecture on the topic for all participating students was held via the Zoom video conferencing tool. A typical task had 5-7 challenges accompanied by a variety of scaffolds. A task also required the students to reflect on how they used CT skills in their work. During class hours, the students split into breakout rooms using Zoom and worked on a task in small groups. The teacher's role was to guide them in organizing their self-advancement through the task. The solutions to the task were submitted using the Google Classroom learning management system.

An example of a multidisciplinary challenge is as follows. The students were given a partially finished, two-player game in the Scratch programming environment [24]. Each of the players controlled a different flying object. The game had several entities representing clouds in the sky. The goal was to reach a randomly picked cloud before the opponent. For the math component, they were asked to explain why the flying objects reached a maximum speed and why the speed declined slowly once a player stopped touching the controls. For science, they were given learning materials about cloud types specifying the attributes of the cloud, such as typical height and appearance. This aided the students to program additional clouds for which they used their skills in CS. The final part of the challenge asked students to alter their existing game into a different theme in science or math instead of clouds. See Figure 2 for snapshots of solutions student submitted as working and functioning games.

Figure 2: Screenshot of two games: for learning geometrical shapes (left) and for learning about the solar system (right) (Captions are in Hebrew)

The final course project is creating an ABMS of a real-life phenomenon. The tool kit created for the students assists them in learning about a phenomenon that happens in Israel at an increasingly alarming rate - many sinkholes are forming in the vicinity of the Dead Sea.

2.4 Pedagogy

The introduction section describes in detail the challenges of remotely teaching critical thinking skills in STEM courses. In addition, several guidelines for succeeding in online remote teaching were described. The goal of the designed course was utilizing those suggestions to overcome the expected challenges, thus developing a new teaching and learning paradigm for remote learning.

The leading pedagogy is the Guided Discovery Learning (GDL) that engages students in appealing problem-solving tasks. This reduces the social isolation of distance learning because the participants solve the problems together in virtual rooms. In addition, the constructionist method is used for students to be highly motivated while they invent new artifacts and take responsibility for their learning.

To overcome a lack of teachers' expertise in CS and CT, the ownership on the various tasks of the Teaching Value Chain was split between the teachers and the experts as follows: 1) 'Direct teacher instruction for students' was split between the experts that created self-explanatory, scaffolded learning materials and the teachers who have led the students in doing the tasks collaboratively. 2) 'Providing students an opportunity to explore content through experimentation, discussion, guided practice, and independent work' was also divided between the teachers who oversaw the process and the experts in charge of the scaffolds. 3) 'Assessment of what students have learned and what they are still struggling with' was conducted by the experts who have altered the modules, lectures and special day activities for the next round of instruction and exploration. In addition, the CS tasks enabled students to check their work and verify by themselves if they were on track.

These enabled teachers to focus on what they know very well and feel comfortable with, leading their students to organize the learning process and solve interpersonal conflicts.

2.5 Data Collection

Data was collected and analyzed using several approaches:

1 Comparison of pre-course and post-course questionnaires.

2 Tasks solutions submitted by students. These include shorts tasks created on special event days and tasks spanning over several weeks. The solutions included written answers, software artifacts, and videos the students created.

3 Semi-structured interviews with selected students at the end of the course.

4 In-class observations of Unit #4 when students presented their artifacts to their classmates.

5 An analysis of the simulation projects submitted by students.

The intervention course at hand was held in remote settings. We also compared student results of the course at hand with results of an ABMS course that was teacher-guided in an in-class learning format [25].

Semi-structured interviews provided in-depth insight into how the students understood and used CT skills in life, how they used those skills while building their artifacts in Unit #4, and understanding ABMS and science. Five Hebrew-based interviews, lasting 30-45 minutes, were conducted with students from five experimental classes within one day post-unit. Interviews were carried out via the Zoom video conference tool with 3-4 student participants. The videos were recorded and transcribed, and later analyzed using quantitative evaluation. The students had volunteered to participate when offered by their teachers. The semi-structured interview started with ice-breaking questions such as why they chose to participate in the course and later moved to discuss the subject it was intended to cover. The interviews shed more light on the questionnaire's results and artifacts created, illustrating the students' responses, and resulting in a better understanding of students' gains, as will be discussed in the next section.

Overall, both qualitative and quantitative evaluations are part of the mixed methods research methodology.

3 RESULTS

This chapter will describe the results of the intervention research based on a significant amount of data. This paper reviews the results analyzed so far: a comparison of science learning using ABMS between traditional and remote learning settings.

The peak of the course is its 4th module. It comprises student creation of an agent-based model and simulation of how sink holes are formed around the Dead Sea in Israel. To succeed in the task, they decompose the phenomenon into its sub-parts and processes. This module was taught in two settings: in 2019, in an in-class setting [25] and in 2021, in a distant-learning setting. The results of both research sessions were compared and provide the following outcomes.

A questionnaire distributed at the end of the course consisted of two types of questions: those that tested knowledge and those that tested analysis skills. For instance, one of the knowledge questions was: "Is one of the reasons that sinkholes are formed related to a decrease in the sea level?". This question is a true/false question, the correct answer being “true”. An example for a question which tests scientific analytic skills is: "If the Dead Sea were to be filled up with water from the slightly salty Mediterranean Sea, will sinkholes continue to be formed? Explain your answer." This question was a profound one for the researchers because of several factors. First, there is no correct answer. Second, the plan of building a canal from the Mediterranean Sea to the Dead Sea was not part of the learning materials, so students had no previous knowledge on the matter. Thirdly and most importantly, to explain their answer, they needed to relate to the sinkhole formation process and the elements involved in its formation. This question reflects their science analytical skills because the agent-based simulation mechanics they created is based on agents and interactions between them. Eleven patterns emerged from students' answers. Four of them are related to elements: ground, salty water, sweet water, salt layer in the ground. An additional six related to interactions between the elements: water trickling in the ground, change of sea level, absorption of salt by sweet water, land falling, sweet water forming over saltwater. The eleventh pattern used by students to explain their answer was to reference other seas.

An answer was scored according to how many patterns it consisted of. After coding each question, the score range was 0 – 6: 0 means the student did not answer; 6 means that the answer consisted of 6 patterns. An example of an answer from a 6th-grade student which was scored with 6 points (translated from Hebrew): "In my opinion, if the water from the Mediterranean comes, new sinkholes will be formed because the water in the Dead Sea is much saltier than the water in the Mediterranean, and sinkholes are formed as a result of less salty water dissolving the salt in the ground and the ground collapsing."

To compare the in-class and remote-learning settings, we utilized 5th-grade student answers only because the traditional class students were all from 5th-grade. Figures 3 and Figures 4 break down the level of success each setting had according to the percentage of students in each score level.

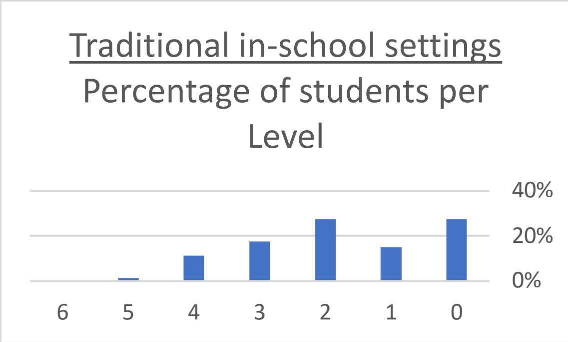

Figure 3: Skill level of in-class settings

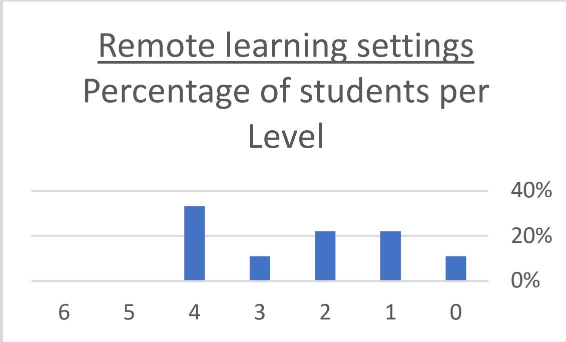

Figure 4: Skill level of remote-learning settings

The scoring and grouping of the students into three levels shows that the remote-learning settings scores were higher.

- More in-school students (43%) had lower skill levels, scoring 0-1 than remote students (33%).
- More in-school students (45%) had medium skill levels, scoring 2-3 than remote students (33%).
- Fewer in-school students (12%) had high skill level, scoring 4-5 than remote students (34%).

Since students at a lower level might have missed the question altogether or were unwilling to make an effort to answer it in detail, we also looked at an additional measurement: the average score of students who had medium and high levels. This showed an average score of 3.5 for remote students and 3.1 for in-class students. In conclusion, in the three metrics showed that the remote students achieved better scores than the in-class students.

So far, we have analyzed skills, and next, and we outline several more measurements. The measured science knowledge between the two learning settings showed similar results. Both had a score of 89 on a questionnaire consisting of 5 knowledge questions. Also, the motivation factor was almost the same: 4.0 out of 5 for in-class and 4.1 for remote students. Their course value view, showing how much they perceive the course as contributing to their understanding of the sinkhole phenomena, was also similar: 4.1 out of 5 for in-class and 4.2 for a remote. The use of simulation in learning was low in both settings. On a scale of 1-5, students related to the question: To what extent did you use simulations this year in science class? The in-class average was 1.7, and the remote-class had 2.1, which indicates greater use of media-rich tools in remote learning over in-class.

An additional result relates to a question asking the students to mention another science topic they have learned this year which can be learned using an ABMS constructionist methodology. In addition, they were asked to describe the ABMS for their chosen phenomena. This relates to students' critical thinking because they need to transfer ABMS characteristics to another content. In the in-class settings, only 54% of them were able to do that, while 46% either did not answer the question or named the interventions activity as the topic that can be learned with ABMS. This could have been caused by not understanding the question. For the 2021 research, the question at hand was revised, splitting it into two separate questions: 1) name a phenomenon that you think can be simulated with ABMS, 2) specify the agents. It resulted in rich results. 93% of the students named a phenomenon they deemed suitable for ABMS. A few examples of phenomena names that students described: state of matter, water cycle in nature, global warming, wind formation, tornado, fire eruption, cloud formation, predator and prey, evolution, thunders, blood cells, earthquake, rock formation, rainbow, volcano eruption, flowers wither, tide, moisture, and dry air. One student wrote: "There is a natural phenomenon that hot air comes out of the ground. It happens when there is a really hot day, so the hot air enters the ground, and then in the evening it starts to get cold, so the hot air comes out of the ground. There are three agent types: one represents earth particles, one represents the heat coming out of the earth, and one represents the cold air". 83% of the students were able to detail agents they believe should be appropriate for an ABMS of their phenomenon.

Observations were conducted when the students presented their ABMS sinkhole artifacts. Qualitative assessment displayed both groups were able to articulate the mechanics of the phenomenon well, explaining the elements involved in sinkhole formation and their interactions.

4 CONCLUSIONS

The term 'remote learning' became common during 2020 and 2021. Post COVID-19 pandemic, many argue that the trend toward blended learning will continue. This paper describes a research project studying elementary school students' gains in science learning and computational thinking (CT) skills. The participants underwent a unique teacher-led course in remote learning settings. The course content was multidisciplinary, involving math, science, and computer science. The leading pedagogy was the Guided Learning Discovery (GDL) pedagogy involving constructionist activities. The final course task was to form an agent-based module and simulation (ABMS) of a real-life phenomenon.

The results of this intervention were compared to the results of the in-class course we studied before the pandemic [25]. Both courses had similar characteristics in terms of content, goal, and participants. They mainly differed by their settings: distant learning vs. traditional in-class learning. Analysis of the study's results indicates that constructing ABMS improved students' understanding of the science content. Students were able to articulate the mechanics of complicated real-life phenomena. Furthermore, they demonstrated an ability to harness the agent-based methodology as a mechanism for analyzing other real-life phenomena such as the water cycle or how flowers wither. Comparing between the remote learning study of 2021 and the in-class study of 2019 showed both having the high motivation to learn by students and science knowledge gains. The remote learning study found slightly favored results as for students' analytical science-reasoning.

Given the multitude of challenges, as described in academic literature, regarding remote learning of critical thinking skills in STEM, one should wonder: can remote learning have similar or even favorable results to traditional classes? The first generation of remote learning in k-12 schools focused on presenting physical classroom-based instructional content over web conferencing tools. Furthermore, first-generation remote learning programs gave rise to realize that a single mode of instructional delivery may not provide sufficient choices, engagement, social contact, relevance, and context needed to facilitate successful learning and performance. Following guides of UNESCO for remote learning, while using GDL and constructionist pedagogies, the second wave of k-12 remote learning was embedded into a STEM course. It includes problem-based learning, student-led hands-on activities, and the creation of artifacts in a social setting. Furthermore, the ABMS approach connected directly to student's interests enabled extended investigations as well as a deeper understanding of the content. These could perhaps explain why the distant learning format did not shortfall that of the traditional learning format.

Some countries are lacking sufficient CS teachers or teachers trained in CT. In addition, appropriate lesson plans for a unified STEM course in a remote learning format are in short supply. The paradigm used to create the course at hand could assist in reducing those challenges. It included relieving teachers of some of their duties and sharing them with a team of experts. CT is an emerging skill in STEM learning. It requires school systems to give increased attention to promoting student engagement in CT activities alongside ways to promote a deeper understanding of science, math, and computer science. There should be a practical program for school STEM courses with education embracing embedded learning.

REFERENCES

[1] Dron, E., Sarakatsannis . J, Panier. F, (2020). *Back to school : Lessons for effective remote and hybrid learning*. Retrieved May 1, 2021 from https://www.mckinsey.com/~/media/McKinsey/Industries/Public and Social Sector/Our Insights/Back to school A framework for remote and hybrid learning amid COVID 19/Back-to-school-A-framework-for-remote-and-hybrid-learning-amid-COVID-19.pdf.

[2] Howells, K. (2018). The future of education and skills: education 2030: the future we want.

[3] Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM education*, *3*(1), 1-11.

[4] Russo, J., Bobis, J., Downton, A., Livy, S., & Sullivan, P. (2021). Primary teacher attitudes towards productive struggle in mathematics in remote learning versus classroom-based settings. *Education Sciences*, *11*(2), 35.

[5] Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining computational thinking for mathematics and science classrooms. *Journal of Science Education and Technology*, *25*(1), 127-147.

[6] Gero, A., & Levin, I. (2019). Computational thinking and constructionism: creating difference equations in spreadsheets. *International Journal of Mathematical Education in Science and Technology*, *50*(5), 779-787.

[7] Gero, A., & Levin, I. (2018). Construction of difference equations in spreadsheets as a means of developing computational thinking among students. In *Edulearn 18. 10th International Conference on Education and New Learning Technology (Palma, 2nd-4th of July, 2018): conference proceedings* (pp. 9293-9296). IATED Academy.

[8] Shamir, G., & Levin, I. (2020, July). Transformations of computational thinking practices in elementary school on the base of artificial intelligence technologies. In *Proceedings of EDULEARN20 Conference* (*Vol. 6, p. 7th)*

[9] *Ministry of Education Israel. (n.d.). Computational Thinking*. Retrieved May 1, 2021, from https://www.theoceancleanup.com/updates/whales-likely-impacted-by-great-pacific-garbage-patch/

[10] *Ministry of Education Israel. (n.d.). Distance teaching and learning: lessons from a period of school closure following COVID-19 pandemic*. Retrieved May 1, 2021, from https://meyda.education.gov.il/files/Rama/Remote_learning_Teachers_Survey_2020.pdf

[11] Kapur, M. (2010). Productive failure in mathematical problem solving. *Instructional science*, *38*(6), 523-550.

[12] Clarke, D., Roche, A., Cheeseman, J., & Van Der Schans, S. (2014). Teaching Strategies for Building Student Persistence on Challenging Tasks: Insights Emerging from Two Approaches to Teacher Professional Learning. *Mathematics Teacher Education and Development*, *16*(2), 46-70.

[13] Lye, S. Y., & Koh, J. H. L. (2014). Review on teaching and learning of computational thinking through programming: What is next for K-12?. *Computers in Human Behavior*, *41*, 51-61.

[14] Papert, S. (1993). *The children's machine: Rethinking school in the age of the computer*. BasicBooks, 10 East 53rd St., New York, NY 10022-5299.

[15] Ah-Nam, L., & Osman, K. (2017). Developing 21st century skills through a constructivist-constructionist learning environment. *K-12 STEM Education*, *3*(2), 205-216.

[16] Yurniwati, Y., & Hanum, L. (2017). Improving mathematics achievement of Indonesian 5th grade students through guided discovery learning. *Journal on Mathematics Education*, *8*(1), 77-84.

[17] Mayer, R. E. (2004). Should there be a three-strikes rule against pure discovery learning?. *American psychologist*, *59*(1), 14.

[18] Adelia, W. S., & Surya, E. (2017). Resolution to Increase Capacity by using Math Students Learning Guided Discovery Learning (gdl). *International Journal of Sciences: Basic and Applied Research (IJSBAR)*, *34*(1), 144-154.

[19] Levy, S. T., & Wilensky, U. (2011). Mining students' inquiry actions for understanding of complex systems. *Computers & Education*, *56*(3), 556-573.

[20] Levin, I., & Levit, E. V. (1998). Controlware for Learning Using Mobile Robots. *Computer Science Education*, *8*(3), 181-196.

[21] Levin, I. (1993). Matrix model of logical simulator within spreadsheet. *International Journal of Electrical Engineering Education*, *30*(3), 216-223.

[22] Kong, S. C., & Abelson, H. (2019). *Computational thinking education* (p. 382). Springer Nature.

[23] National Research Council. (2010). *Report of a workshop on the scope and nature of computational thinking*. National Academies Press.

[24] Maloney, J., Resnick, M., Rusk, N., Silverman, B., & Eastmond, E. (2010). The scratch programming language and environment. *ACM Transactions on Computing Education (TOCE)*, *10*(4), 1-15.

[25] Shamir, G., Tsybulsky, D., & Levin, I. (2019, May). Introducing Computational Thinking Practices in Learning Science of Elementary Schools [Research-in-Progress]. In *InSITE 2019: Informing Science+ IT Education Conferences: Jerusalem* (pp. 187-205).