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Can you create? Visualising and modelling real-world mathematics with technologies in STEAM educational settings

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In the past three decades, and especially accelerated during the Covid-19 pandemic, technology-assisted learning and teaching, and particularly in our case dynamic mathematics software in science-technology-engineering-arts-mathematics (STEAM) settings are becoming increasingly important. More recently, the development of more advanced mathematics-related technologies such as augmented reality, computer-aided design software, 3D printing, and global positioning system-enabled visualisations and modulations of mathematical concepts and the development of different behaviours in learning and teaching. These advanced technologies could enable students to more easily become creators, develop simulations, and utilise multiple representations of real-world or abstract objects by applying their mathematical and modelling skills. In addition, through such approaches, mathematical modelling and visualisations facilitated crossing subject boundaries in Science Technology Engineering and Mathematics (STEM) and more recently STEAM fields. Consequently, there is an increased amount of research connecting students' visualisations and modelling of their real-world environments and working on real-world problems with these technologies. In this paper, we reviewed promising research within the past two years on the uses of advanced technologies in mathematics, and in a broad sense STEAM education, circling around the question 'Can you create?' and how such novel approaches could impact behaviours of students and teachers in the current educational circumstances.

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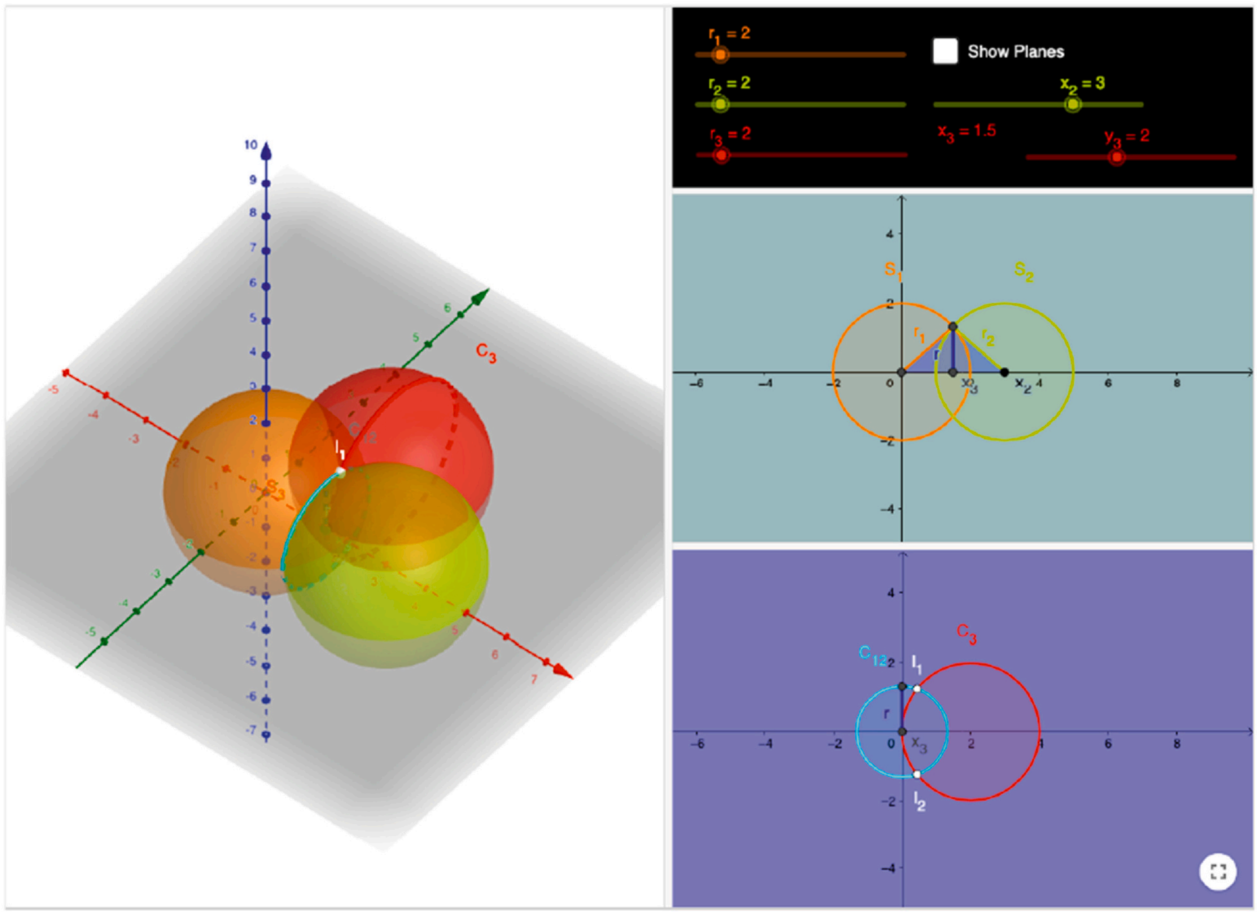
The evolution of technologies in mathematics education

Educational technology in supporting learning and teaching in mathematics, and broadly science-technology-engineering-arts-mathematics (STEAM) education, went through major evolution during the past three decades and especially this change accelerated during the Covid-19 pandemic, making substantial impacts on education. One of the first mathematics education-oriented software was dynamic geometry initially developed in the late 1990s. Research showed that dynamic geometric software (DGS) [1] has profoundly transformed mathematics education; students engage in active visualisations of mathematical concepts and graphical modelling. Earlier, the relatively static paper-pencil or blackboard-based educational approaches were supplemented with live and dynamic visual elements and soon proved to be advantageous for mathematical learning [2]. DGS then advanced to more general dynamic mathematics software (DMS) adding new opportunities for teaching and learning over the past two decades, but during the Covid-19 pandemic offered even more potential to enable and enhance remote teaching [3]. DMS facilitated mathematical visualisations of a variety of mathematical objects in two dimensions from primary to university level teaching; for instance, students could rapidly model and represent mathematical concepts and understand solving paths for linear equations, coordinates and other mathematical patterns [4] paper-pencil approaches (see Figure 1).

With the rapid advancements of DMS, two-dimensional representations evolved in three dimensions allowing an even more precise visualisation for students to better understand the properties of solids [5]. Following a recent meta-analysis of DMS in class sustainably developed mathematical skills for graph modelling [6••]. Furthermore, such learning experiences were integrated into automated tutoring systems [7] to foster conceptual knowledge in mathematics to enhance developing patterns, which can be used as an addition to textbooks or to support existing pedagogies in class [8]. Over the years, DGS in many cases were embedded in learning environments, supplemented with video tutoring or discussion platforms, to extend tasks, foster group activities, or promote metadiscussions [9]. Moreover, more complex mathematical reasoning, such as the golden ratio or

Figure 1



Current Opinion in Behavioral Sciences

An interactive GeoGebra activity is available (https://www.geogebra.org/m/hfujpcyw).

Fibonacci sequence, can be illustrated in various ways with DGS and linked to real-world objects, fostering critical thinking in mathematics education [10]. DGS clearly made educational progress towards National Council of Teachers of Mathematics technology standards [11], for example, enhancing problem-solving or representation skills in technology environments could be clearly observed [12]. Thus, overall research showed that DGS and DMS could support mathematics education valuably, but the rapid developments of new technologies in the past years opened new horizons.

The arrival of new technologies

Although teaching with DMS was dominant in mathematics education, several new technologies found their way into classrooms and extended opportunities for learning and teaching. For instance, augmented reality (AR) enabled the *in situ* visualisation of shapes, objects or functions in 3D [13,14•] within real-world environments; computer-aided design (CAD) software to model geometric shapes with ease [15]; 3D Printing to recreate real-world objects from virtual designs [16•,17] and global positioning system (GPS) technology enables the connection of location coordinates in and outside of classrooms [18•].

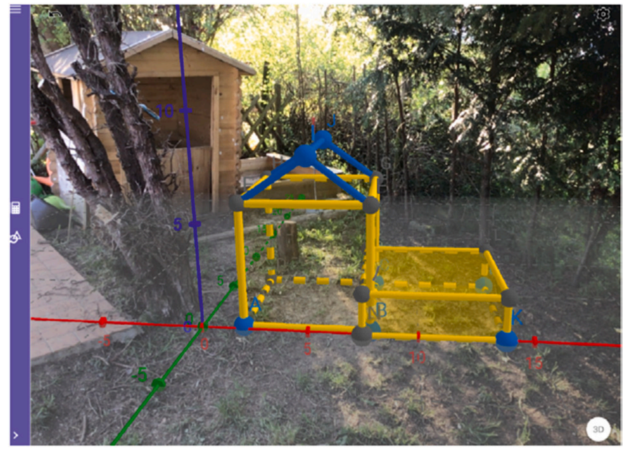
Such technologies opened novel perspectives to connect mathematics directly with students' immediate living environments and actively experience mathematics in and outside of traditional learning settings. For example, visualising geometric shapes in the classroom with AR, recreating real-world objects with mathematical concepts with CAD software and 3D printing these objects could demonstrate the immediate applications of mathematics for students as well as connect it with other Science Technology Engineering and Mathematics (STEM) disciplines [19]. Students can create, compare and modulate their environment with mathematical content through the use of various technologies and connect them across subject boundaries (e.g. recreating cultural artefacts, identifying and continuing patterns of sculptures or constructing historical machines). In this educational context, students connect their mathematical knowledge and skills directly to STEAM disciplines with creative approaches [20] utilising opportunities for new technologies.

Despite such opportunities, existing theories on problem-solving [21] and mathematical modelling [22•] suddenly needed to be applied to newly emerging technologies in education. Students have had opportunities to create or modulate 3D objects in the real world [16], contributing to the changing roles of students from consumers to creators of knowledge [9]. Such changes in knowledge creation along with students' increased motivations in our studies and examples below offered new perspectives for teaching and learning mathematics [23]. Students could apply their problem-solving skills or mathematical modelling in their surroundings and this process made abstract mathematical concepts more tangible for their learning. Technology-enhanced mathematics courses were mostly based on abstract or pure mathematical tasks, not necessary connection to applying concepts in everyday situations, In addition, 2D visualisation rather than 3D was the norm of problem-solving and posing. However, as already mentioned, earlier with the emergence of AR, CAD software, GPS technology, or 3D Printing, new opportunities opened to integrate *in situ* real-world experimentations inside and outside of classrooms. For example, in the paper of Haas et al., instead of calculating the volume of a given transport container in class hypothetically with 2D, students could go outside instead to take measures of objects in 3D, recreate the volume with AR by connecting virtual and real-world information and give a rigorous and exact value of an existing problem [24]. In the upcoming section, we will highlight a selection of research articles offering promising results and with the application of new technologies students to become creators and active solvers of real-world problems.

Creating visualisations with augmented reality

As an element of mixed realities, AR allows students to connect physical objects with the digital world, making digital objects appear as representations in the real world. This new representation may allow students to gain a better understanding of the roles of mathematical objects, for example, connecting two-dimensional geometry with 3D spaces [25]. In Figure 2, students used a variety of geometric shapes and lines, calculated volumes, and constantly verified their process with AR software. Thus, students were able to compare their work directly with the expected results during their solution processes; in this case, the reconstruction of a wooden house and a sandpit. Moreover, students were highly motivated in learning mathematics while using these new technologies [26]. AR could also allow the further transformation of traditional learning supports, adding AR supplements to books, manipulatives, and other learning visualisations [27•]. AR is used on mobile devices, tablets or smartphones, allowing additional visual information in class and making interactive learning and new opportunities for collaboration possible. "The collaboration patterns showed that students played this AR game in a way similar to a traditional real-world game. Students spent significantly more time in the collaboration game" [28]. Hence, AR mathematics can be presented more organically to culture or to other disciplines, for example, the study of El Bewedy et al. [29], used AR and 3D printing to make students understand patterns based on ancient Egyptian cultural architecture [29]. In terms of learning behaviour, the research highlighted that students could gain higher motivation and improve long-term understanding and retaining of mathematical concepts [30,31].

Figure 2



Current Opinion in Behavioral Sciences

Use of AR to reconstruct a wooden house and a sandpit [17].

Creating with computer-aided design software and 3D printing

The use of AR is recently combined in mathematics education with CAD software to design or redesign shapes in geometry and to make connections directly to the real world [32]. Students manipulate mathematical objects with CAD software to design; for example, cultural or historical artefacts, such as a catapult or bridge [16•]. The functionalities of these artefacts can be then tested in real settings and discussed by focusing on mathematical ideas (e.g. problem-solving, representing or transformations of initial concepts) then these objects were printed with a 3D printer [9,16•,33] or a 3D Pen [34], further enhancing students' mathematical understanding with possible

Figure 3

Current Opinion in Behavioral Sciences

Students design a cultural artefact (egg cup) from drawings [17].

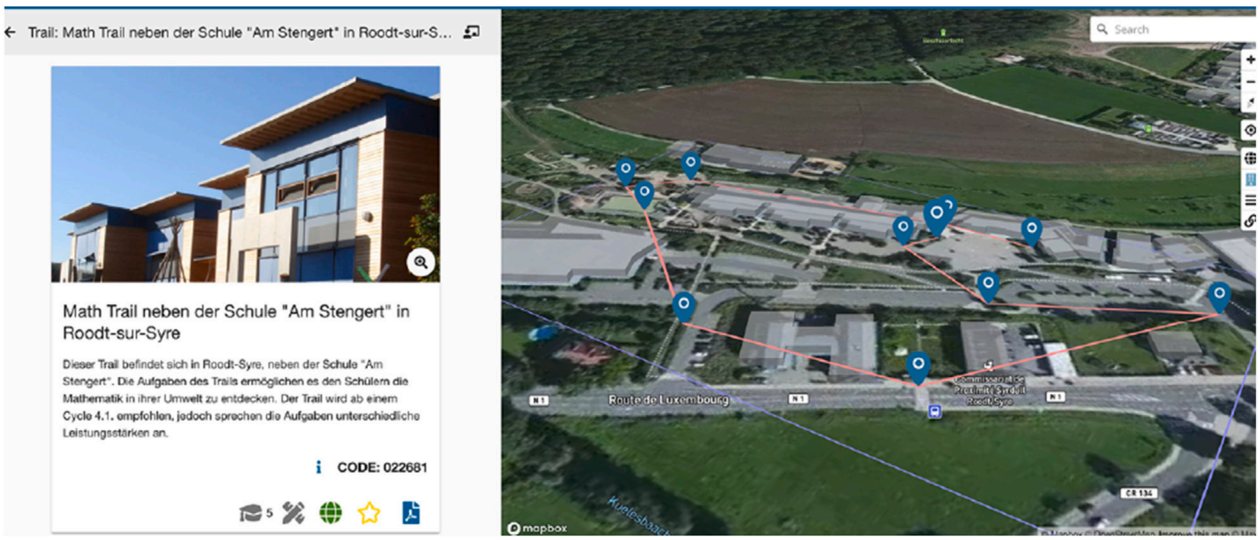
tactile perceptions. In addition to the mathematical content, students learn to use 3D printing, and this is becoming an important part of education in the near future [35].

In Figure 3, we can observe possibilities to learn to transform the 2D representation of geometry to 3D. In addition to mathematics education, STEAM educational approaches will likely benefit positive effects on students' learning behaviours with such new technologies as 3D printing [36•,37]. For instance, CAD or 3D printing uses resulted in engaging, self-directed, experiential-orientated processes, enhancing students' learning and developing their critical thinking [38]. Besides different learning behaviours, 3D printing could enable; for example, designing tactile graphics [39] for and with students bringing a promising alternative for students with special needs. The creative process has also been shown to enable students to understand complex mathematical concepts in calculus or advanced geometry by printing related 3D models [40]. As shown in research, CAD and 3D printing could bring more experiential learning and active discoveries into mathematics and STEAM education.

Solving outdoor tasks with global positioning system technology

While 3D printing and CAD software allow the reproduction or creation of objects with mathematical concepts in class, recent papers also highlighted opportunities for GPS technology to enable the learning and teaching of STEAM ideas beyond classroom settings [17,41]. One of these GPS tools is MathCityMap (www.mathcitymap.eu) that enables the designing of outdoor trails in which tasks are placed on certain spots and can be traced with GPS-enabled devices and with the MathCityMap app [19].

Figure 4



Current Opinion in Behavioral Sciences

Math trails route map and the app displays 3D objects that resemble the target object [17].

As shown in Figure 4, students can follow a trail on a map and can navigate within the app. Once students reach a GPS location, they can access the task at the location. For instance, in this example in Figure 4, students should measure the height of a building without a traditional measuring tool, engage in reasoning, experimenting and observation, and recreate the identified objects with AR or solve problems with the graph theory [42]. Mathematical concepts can be transposed directly into the real world (e.g. buildings, places or art objects) and students should model the given tasks with a variety of technology tools. In the presented example (Figure 4), a combination of technologies with AR and GPS technologies assists students' activities. Thus, findings indicate that AR bridges the gap between the real and the virtual in a continuous way; AR displays objects and concepts in different ways and angles which helps the students to more easily understand geometric concepts, which seems likely to be helpful for students to connect geometry with real-world objects [43]. Furthermore, solving mathematical tasks in a real-world context could develop gestures, foremost deictic and iconic [44] advantageous for mathematics learning. Similarly to 3D printing, these outdoor tasks and trails with GPS found their way into higher education mathematics teacher education offering new opportunities for future teachers [45••].

Conclusions

Technologies are already transforming learning, teaching, and teacher education, and it is likely that the rapid development of technological tools will dominate changes in future mathematics and in a broader sense STEAM education. All of the mentioned technologies (DGS, AR, CAD, 3D printing and GPS) already enabled new learning behaviours and novel teaching opportunities [46,47]. Moreover, remote teaching during the Covid-19 pandemic showed the importance of supporting students with technologies, creating active learning environments and offering physical and virtual guidance for students and teachers [48]. Teaching at a distance or schooling at home [49] brought new technology-enhanced forms, with new opportunities in STEAM education. For instance, the emergence of new technologies enabled changes and enhancements of already popular pedagogical approaches such as flipped classrooms [50,51]. In a flipped classroom approach, students review new content before classes in a self-paced manner and usually using videos, the new technologies that we outlined above offer possible alternatives for more active teaching approaches. In sum, technology has been important for a long time in STEAM education, and new technologies enable new teaching and learning opportunities and behaviours. In this paper, we showed examples of novel educational approaches that are already under research. However, we need to be aware and prepare teachers for utilising even more new and rapidly changing technologies in educational practices. Therefore, investing in teacher education with awareness of changes, resources, and pedagogical development is becoming even more important. We believe that technology will become an even more essential element of education, and the evolution of technology will affect learning behaviours [52] in STEAM education both in and outside of classrooms.

Data Availability

No data were used for the research described in the article.

Declaration of Competing Interest

None.

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