# Can STEAM-Based Learning Improve the Skill's of 21st Century Student Post Pandemic?

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## Abstract

**Background:** During the pandemic caused by the COVID-19 virus, schools were forced to close, which resulted in a learning loss, particularly for students. After the pandemic, education ought to put more of an emphasis on the interconnected aspects of student growth. Learners could get a comprehensive understanding of the issue by applying this strategy and analysing the problem from a variety of perspectives in order to develop a variety of potential solutions. To acquire knowledge, one needs to be in the right environment to investigate a variety of phenomena (the world outside the classroom). Therefore, in order for students to be prepared for life in the 21st century, they need to be proficient in what are known as the "4 Cs" skills. These skills include communication, critical thinking, problem solving, creativity, and collaboration.

**Objectives:** The present literature review examines the potential advantages of STEAM-based learning for preparing students to meet the challenges of the 21st century.

**Methods:** This study was conducted by reviewing journals relate to the STEAM for education Evidence from a variety of literatures demonstrates that the STEAM approach can help students develop the skills and capabilities necessary to address the challenges of the 21st century.

**Results:** Education in the fields of science, technology, engineering, art, and mathematics (STEAM) is ideally suited to meet the challenges of both the post-pandemic era and the 21st century. STEAM has the potential to incorporate a wide range of subject areas, maintain its reliance on technological resources, and provide assistance for the implementation of a variety of educational strategies.

**Conclusions:** Evidence from a variety of literatures demonstrates that the STEAM approach can help students develop the skills and capabilities necessary to address the challenges of the 21st century.

***Keywords:*** STEAM, pandemic, 21st century skills, learning, educational

## 1. Introduction

Acute respiratory syndrome is an infectious disease caused by the corona virus. On January 30, 2020, the World Health Organization (WHO) declared the corona virus outbreak a Global Health Emergency (PHEIC). On March 2, 2020, this epidemic reached Indonesia. Since March 15, 2020, the government has issued physical distancing rules that require people to maintain a safe distance and limit outdoor activities to prevent the spread of COVID-19 [1]. Since then, the entire order of life has begun to change, including education. The COVID- 19 pandemic has significantly impacted the transformation of face-to-face learning activities into online learning activities. In order to

protect themselves and those closest to them from exposure to the virus, teachers, students, and parents must be able to adapt and learn independently at home. However, not all students are easily adaptable to online learning [2].

During the lockdown, many countries were forced to close their schools for an extended period of time. The loss of learning during the Covid-19 pandemic resulted in particular student losses [3]. Dutch elementary school students study fewer hours than the previous year [4]. In some countries, the education gap between rich and poor students is caused by learning loss, only about 10% of children in low-income countries can read and comprehend stories [5]. In Europe, the standard deviation of students from the class of 2020 decreased by 0.19 in mathematics and 0.29 in Dutch subjects [6]. In the United States, students in grades 3-8 struggle with reading and mathematics [7]. Meanwhile, the effect of learning loss in African nations is that students who fall behind their peers are unable to pursue their abilities [8].

Lockdown affects the mental health of students, parents, teachers, and all education actors, in addition to their academic performance [9]–[11]. According to research conducted in Shanghai, students suffer from anxiety, stress, and depression [12]. In Japan, school closures led to hyperactive children and adolescents due to lack of attention, causing parents to experience elevated levels of anxiety, depression, stress, and other negative emotions [13]. The results of the study indicate that school closures have negative effects not only on learning outcomes but also on all education actors.

According to Indahri (2020), Indonesian children's lack of understanding of the material, inadequate internet networks, and disinterest in learning are obstacles to online education [14]. As a result of inefficient material delivery and learning time, some students enrolled in online learning do not comprehend the provided content. This impacts the students' capacity to comprehend the material, which consequently declines. The quality of education in Indonesia has deteriorated, and the public believes that education during the pandemic is not superior to its previous state [15]. Changes to the learning process are also inconsistent with the 2013 curriculum, which emphasises student engagement. The instructor only presents the material through lectures and then assigns homework without material reinforcement. Meanwhile, Effective instruction allows learners to comprehend and master the concept of knowledge [16], including the use of media, which distinguishes student achievement [17] and their character [18].

After the Covid-19 pandemic, educational institutions face numerous obstacles in providing education, such as the knowledge gap of distance-learning students, might result in a significant learning loss for students in basic education. Getting used to returning to normal activities requires considerable time and effort. Implementing post-pandemic learning may also creates a conflict between attaining achievement standards and addressing health concerns. The learning that has begun raises student achievement to the initial level, while face-to-face implementation remains constrained in terms of both the number of students and the duration of learning [19].

These obstacles must be addressed prudently. The government, students, and educational institutions must develop and implement strategies to address these obstacles. Faturohman explains that continuous improvement policies can be implemented as a viable strategy [19]. To ensure that post-pandemic learning activities do not appear to be stagnant, the government must evaluate and

continue formulating its standards. In addition, regular and continuous learning assessments must be conducted to adjust student achievement standards.

This pandemic crisis provides a general outline of the future education system that utilise technology. The learning process must be able to adapt to the needs and demands of the times; education is no longer confined to the classroom, but can now be accessed at any time and place [20]. Education continues to develop in response to the needs and trends of the times hence numerous learning methods have evolved to accommodate the societal era 5.0 [21]. Learning for the 21st century prepares recent generation, who were born during a period of rapid technological advancement that affects all aspects of life. The 21st century learning system is a transition that requires schools to shift from a teacher-centred to a student-centred learning approach and its assessment [22].

Future demands necessitate that students possess the abilities to think and learn. The "4Cs" of 21st century learning are commonly referred to as "21st century learning characters" (communication, critical thinking and problem solving, creativity and innovation, and collaboration). Students are expected to possess all of these skills, so educators must develop a lesson plan that includes activities that foster their development. The implementation of post-pandemic learning must not impede the advancement of technological comprehension. Educators must also be able to increase student interest in learning by implementing learning innovations and utilising assessment results. The implementation of the above-described strategy necessitates an approach to learning that is intuitive, innovative, and in step with the times. This is intended to enhance post-pandemic learning and cultivate various 21st-century skills that students must possess.

Science, mathematics, engineering, and technology education has become a global priority [23]. The United Kingdom has proposed a curriculum that integrates science, technology, engineering, and mathematics (both inside and outside schools) [24]. Germany established a national STEM forum to promote STEM education at all levels. The South Korean government has allotted a sizeable education budget to support STEAM [25]. All subjects in South Korea are required to incorporate a STEAM approach, with 'convergent education' referring to the development of new concepts [26]. All efforts in developed nations to implement STEAM-based education are aimed at meeting the challenges of the 21st century, which require STEM workforce support to overcome global problems and STEM literacy in the new era [23]. Indonesia should also apply the STEAM (Science, Technology, Engineering, Art, and Mathematics) approach to education in order to meet the challenges of post-pandemic education as well as those of the 21st century. Through the STEAM methodology, students are encouraged to cultivate an inquisitive mindset by asking questions so that they can construct knowledge by exploring, observing, discovering, and investigating how things function [27].

Based on the explanation, it is essential to understand the impact of the STEAM approach in education as the answer to the post-pandemic problem. This discovery can be used as the solution to the post-pandemic educational challenge.

## 2. Objectives

This article was written to examine post-pandemic educational challenges and the impact of STEAM-based education on the skills of 21st-century students.

## 3. Methods

This paper was compiled using the method of literature review. All paper related to the topic were collected and used to be reviewed become a mini narrative review.

## 4. Results

### 21st Century Learning

Schools were described differently in the 20th century than they are today. Rarely do student activities involve collaboration. As the primary source of education, teachers continue to be the primary focus of classrooms. In contrast, to prepare students for the 21st century, the educational process must be able to cultivate character and skills, both from the pillars of education and the skills required in the 21st century [28], [29]. Everyone must have digital literacy, media literacy, information literacy, information technology mastery, and critical thinking skills [30]. As we enter the 21st century, the paradigm of education is shifting from teacher-centred to student-centred, and students must be equipped with higher-order thinking skills. Learning in the 21st century is an activity that integrates knowledge, literacy, skills and attitudes, and technology mastery. Learning and education are not exempt from the use of technology in the modern era.

Multiple countries have conducted research on the use of information technology to support learning in the twenty-first century. Collaboration for 21st century competencies identified six key elements to drive its learning, including the content, context, focusing on core lessons and learning skills, and utilising assessments that measure 21st century skills [31].

Recognizing the complexity of future challenges, UNESCO's education commission recommends four pillars of education that can serve as the foundation of education [32]:

a. learning to know, by exploring knowledge from various sources of information;
b. learning to do, by performing an action or proposing an idea;
c. learning to be, by learning to recognise oneself and adapt to the environment; and
d. learning to live together, so that they can work together, compete in a healthy manner, and respect one another.

Moreover, students must be equipped with the "4Cs" skills [33], namely:

a. Communication, which includes the ability to convey ideas effectively orally, in writing, and non-verbally, as well as listening skills, the ability to communicate with various groups, goals, and cultural contexts, and the ability to use communication tools effectively and efficiently. Despite the fact that only a few professions are based on communication skills, all professions require various forms of communication, such as negotiating, resolving conflicts, giving instructions, giving advice, and building relationships.
b. Critical thinking and problem solving, including the ability to argue persuasively, think systematically, justify and make decisions, and solve problems.
c. Collaboration, including the ability to work together effectively, share responsibilities, be flexible, be willing to help achieve common goals through compromise, and value team members' contributions.
d. Creativity and Innovation is the capacity to think creatively, collaborate creatively, and put creative ideas into practise. There are multiple levels of creativity, including imitation, variation, combination, transformation, and original creation.

## Post Pandemic Education

The outbreak of COVID-19 over the past two years has prompted the majority of nations to lock down all systems, including educational institutions, to prevent its spread. There is no opportunity to establish face-to-face education models in schools and universities [34]. Online platforms and ICT integration facilitate the investigation of numerous educational dimensions [35]. To respond to educational challenges during and after the pandemic, teachers and educational institutions must continue to develop their ICT skills from basic to advanced levels. People have begun to recognise the significance of internalising ICT competencies in education [36]. Furthermore, online collaborative discussions provide the opportunity to consider more participatory educational activities [37].

However, COVID-19 is a significant opportunity to transform the entire education system related to fighting the pandemic in order to create a sustainable future. Our educational practise appears to be paralysed. This is in reference to the practise of producing students with extremely limited knowledge, skills, and moral values [38]. These educational products actually increase the unemployment rate rather than resolving existing issues. The world is plagued by a series of problems that must be resolved by the 21st generation and subsequent generations, as they will be the most affected [38]. Innovative educational models that can address existing issues must be investigated. Therefore, it is essential to develop a transformative vision of education that emphasises 21st-century skills. The purpose of modern education is to impart knowledge and problem-solving skills. Several practises can be used to cultivate the knowledge, skills, and values of learners who can become real-world problem-solving leaders, thinkers, designers, creators, developers, and collaborators. Therefore, in the post-COVID-19 context, practises that have the potential to integrate skills into the learning environment must be implemented.

Technology is not an exception to learning and education in the twenty-first century [39]. Modern ease of access to education appears to be encouraging a new generation that is regarded as intellectually capable. However, many employers have discovered that the younger generation of applicants lacks essential skills, such as problem-solving, critical thinking, and communication, resulting in a skills gap. According to studies, the gap in higher-order thinking skills is widening [40]. One of the reasons is the separation of disciplines. Problems in human existence do not arise in isolation. Thus, multiple perspectives and skills are required to solve a problem. Separating disciplines makes learning difficult because the human brain cannot function in isolation. Integrated learning approaches, namely multidisciplinary, interdisciplinary, and transdisciplinary learning approaches, emerge from this perspective [41].

Post-pandemic education should emphasise the interdisciplinary character of learning. By employing this strategy, students gain a comprehensive understanding of the problem by analysing multiple perspectives to generate alternative solutions. Exploration of various phenomena requires a conducive environment for learning (the world outside the classroom) [42]. This is undoubtedly dissimilar to the conventional learning model that has been widely utilised. Post-pandemic education must employ a participatory learning strategy that emphasises collaboration in exploring problems, examining multiple sources, and identifying potential solutions. Now, students must be empowered to think divergently in order to find solutions to problems, develop prototypes creatively, and effectively implement them.

STEAM education is ideal for addressing the challenges of this post-pandemic period. STEAM can incorporate multiple disciplines, make use of technology, and integrated into various learning subjects and levels of education [43], [44]. In addition, STEAM is viewed as a means of preparing citizens for the professions that continue to expand [45]. Plessis confirms that 75 percent of the fastest-growing occupations require STEM skills [46]. Therefore, education must be conducted in authentic and real-world settings. The STEAM teaching and learning strategy is credited with providing an authentic learning environment in which students directly engage in activities and thoughts with real-world applications. Due to the need to replace some perishable materials and damaged equipment specified in the curriculum policy, practical teaching and learning strategies utilising the STEAM approach can be quite costly [47]. Teachers are expected to be able to innovate and improvise in the beginning of these obstacles by utilising available materials, redesigning experimental procedures, and finding alternatives for hands-on activities [48].

Education in science, technology, engineering, the arts, and mathematics may be viewed as a way of grouping together the same disciplines [49]. However, the STEAM approach and the resulting curriculum innovations are motivated by complex goals, such as the goal to cultivate the innovative abilities of citizens [50]. STEM education aims to integrate multiple subjects into a cohesive curriculum. The essence of STEM education is the development of essential skills for the 21st century, such as problem-solving, curiosity, critical thinking, creativity, imagination, innovation, leadership, teamwork, collaboration, and cooperation, among others [40]. The purpose of these skills is to improve life, therefore, curriculum practises that enable students to apply what they learn in real-world situations are required.

The STEAM pedagogy encourages students to be more proactive and self-directed in their pursuit of knowledge. The experience they have can motivate them to construct a concept of knowledge through observation, investigation, and questioning related to what they wish to learn. This experience can boost the confidence of students. STEAM is ideally suited for curriculum integration in 2013 that incorporates multiple subjects. This approach is applicable to students of all educational levels. Integration of thematically taught subjects at the elementary school level, social studies and science subjects at the junior high school level, and physics, biology, mathematics, and chemistry at the secondary or vocational school level to support STEAM-based learning.

## STEAM Approach

Application STEAM approach in learning can integrate all components. Learning models that can integrate each STEAM component include Inquiry-Based Learning, Project-Based Learning, Problem-Based Learning, and Discovery-Based Learning. The STEAM approach is a combination of STEM by adding art elements in it. Art elements include design, innovation, and creativity. STEAM-based learning is carried out based on 5 areas, namely:

a. Science is about asking questions and finding answers to explain how things work. Science is the process of making observations, making hypotheses, conducting experiments, collecting data, analyzing results, and verifying results. Students are given a stimulus to be able to use a scientific approach in solving various problems in life. Science is physical, approachable and related to children's lives. Science studies about nature, both living and non-living things that can be seen from the sciences of biology, physics, and chemistry.

b. Technology is a vehicle that supports learning to learn effectively. Facilities for object visualization, 2D modelling, 3D modelling, audio and video from several materials help students to learn something as effectively as possible. Technology is very closely related in daily activities, students need skills to develop technological abilities. Students collaborate with friends in using technology to process, convey information, and integrate with science to create new machines and more effective ways of doing things.
c. Engineering is about finding, designing, and creating new work that is a solution to a problem using science, technology, and mathematics. It requires design thinking skills to create extraordinary solutions to problems facing the world.
d. Art is about blending the left and right brain in learning and solving problems. So it's about using imagination and style to create brilliant and innovative things [41]. Students create their findings so that they have aesthetic value so that they can be well received by the community
e. Mathematics, students use a mathematical approach in processing their findings, such as measuring, classifying, classifying and comparing. Mathematics consists of several sub-fields, namely measurement, geometry, classification, number concepts, and arithmetic.

The STEAM approach allows students to connect their existing knowledge of science, technology, engineering and mathematics. Thus, it is expected can increase student learning outcomes. According to Bybee (2010) the purpose of STEAM is that students have an awareness of technology, science, art, engineering, and mathematics to deal with questions and problems in everyday life, and are able to complete and respond to statements related to issues in life. Students are expected to be able to put forward logical ideas and be able to apply them on the basis of scientific disciplines which will lead to the development of an intellectual social environment and become good citizens.

STEAM empowers teachers to carry out project- based learning involving five disciplines (science, technology, engineering, arts, and mathematics) and fosters an inclusive learning environment where all students contribute to learning activities. In contrast to conventional learning models, with the STEAM approach educators unite various disciplines and increase dynamic synergies between processes. Even for students who later do not have a career related to one of the STEAM fields, the skills possessed from STEAM learning can be transmitted to almost all future careers. Implementing STEAM learning properly will prepare students for the rest of their lives, regardless of the profession they choose in the future [27].

The STEAM educational framework is another name for pedagogical innovation [51]. Combining science, technology, engineering, arts and math knowledge and skills will help students understand problems holistically. STEAM education provides a learning landscape characterized by holistic developments in learning. STEAM integrates knowledge, skills, and competencies in problem solving for a sustainable future.

STEAM Improve Critical Thinking & Problem Solving Skill

STEAM represents student-centred, integrated learning. The STEAM approach enables educators to teach with the integration of disciplines that depart from a problem in order to equip students with the skills necessary to solve the problem [52]. Brown et al. (2003) also emphasised that students' learning experiences must be tailored to their experiences and backgrounds so that they can acquire

problem-solving skills relevant to their daily lives. Therefore STEAM can foster problem solving skills in students. Students can use the skills they acquire to solve authentic (real-world) problems and work collaboratively to develop real solutions over time [53]. In STEAM learning, information is formed through collaborative risk-taking and creativity; consequently, students utilise skills and learning processes in science, technology, engineering, art, and mathematics to solve problems.

STEAM has a scientific context, namely scientific inquiry, in which students are prepared and taught to think and act like scientists; therefore, a high level of knowledge, namely mind-on activity, is required [45]. In the STEAM learning process, the emphasis is on hands-on instruction, schema-inquiry, and problem solving that can develop students' internal and external abilities, such as critical thinking, creative thinking, and problem-solving skills [54]. Therefore, STEAM can foster higher order thinking skills in students.

### STEAM Improve Creativity & Innovation Skill

Motivation, cognition, and metacognition are influences on creativity [55]. Nonetheless, creativity is not emphasised in educational programmes. Instead of placing a heavy emphasis on students' performance on standardised tests, all educators must understand and incorporate creativity into the curriculum [56]. It is crucial to increase teacher awareness in order to identify creative thought, disposition, and attitude [57]. STEAM education encourages students' acquired creativity in all disciplines for the completion of projects. The inclusion of "Art" in STEM promotes the growth of cognitive processes that enhance students' creativity [56].

Originally, STEM was transformed into STEAM by combining design, creativity, and innovation, which are elements of art. The inclusion of art in STEM education is intended to enhance students' creativity and innovation, problem-solving abilities, and other cognitive benefits [41]. It can also improve the teamwork, communication, and adaptability skills required for economic advancement [58]. According to research findings, STEAM education contributed to a rise in student creativity [59]. Students can practise 21$^{st}$ century skills, such as critical thinking, creativity, scientific literacy, and science process skills through learning activities [60]. In the STEAM approach, the integration of technology and hands-on activities to build knowledge makes students really enjoy learning activities [61].

### STEAM Improve Collaboration Skill

Future work demands are knowledge-based, inter-disciplinary, and specialised. The complexity of the task necessitates collaboration, as no single employee can possess all of the necessary skills and knowledge [62]. Consequently, work is increasingly performed by teams of individuals with complementary skills and responsibilities [63].

Research has demonstrated that STEAM enables educators to effectively teach using transdisciplinary questions [52]. Students are encouraged to explore all of their abilities in their own way in order to generate diverse ideas and works. Collaboration, cooperation, and communication will emerge as a result of the group-based nature of this instructional method. Students are expected to take personal and interpersonal responsibility for their learning.

The results of the study confirm the benefits of the STEAM approach, namely the enhancement of cooperative learning, group discussion, curriculum-based communication, and problem-solving skills. As a result, STEAM education can foster in children patience, diligence, and tolerance, as

well as responsibility [54]. When interaction in the learning process is effective, the learning and absorption of students in the learning process can be enhanced [64].

STEAM Improve Communication Skill

Communication skills are crucial in a variety of fields, and everyone must pay close attention to their ability to transmit information effectively and with consideration for the audience and the media [65]. Due to the close relationship between these skills and the global economy, employers require communication skills [66].

STEAM education has a significant impact on students' communication skills and conceptual understanding [67]. STEAM demonstrates that science communication can survive and even thrive in a digital environment, according to the study's findings. It is acceptable to support virtual, in-person, or hybrid educational innovation events [68]. According to research conducted in Korea, implementing the STEAM approach in elementary school has a lasting impact. Students believe the STEAM experience better prepares them for college and improves skills like communication and teamwork [25].

## 5. Conclusion

Post-pandemic education should emphasise the interdisciplinary character of learning. The complexity of the 21st century necessitates diverse skills and education as preparation and training for addressing existing problems. In the context of post-COVID-19, it is necessary to implement practises that have the potential to integrate skills into the learning environment. On the basis of the preceding description, the STEAM approach can be used to address the challenges of post-pandemic education. The implementation of STEAM learning has a positive effect on the development of 21$^{st}$ century skills. The STEAM approach enables educators to teach with the integration of disciplines that depart from a problem in order to equip students with the skills necessary to solve the problem. Thus, through the STEAM approach, students can develop the skills and abilities necessary to solve problems of the twenty-first century.

## 6. References

[1] Y. Sumarni, "Pandemi Covid 19: Tantangan Ekonomi dan Bisnis," *Al-Intaj J. Ekon. dan Perbank. Syariah*, vol. 2, no. 1, pp. 46–58, 2020.

[2] A. Marwanto, "Pembelajaran pada Anak Sekolah Dasar di Masa Pandemi Covid 19," *J. Basicedu*, vol. 5, no. 4, pp. 2097–2105, 2021, doi: 10.31004/basicedu.v5i4.1128.

[3] S. P. Zhdanov, K. M. Baranova, N. Udina, A. E. Terpugov, E. V. Lobanova, and O. V. Zakharova, "Analysis of Learning Losses of Students During the COVID-19 Pandemic," *Contemp. Educ. Technol.*, vol. 14, no. 3, p. ep369, 2022, doi: 10.30935/cedtech/11812.

[4] P. Engzell, A. Frey, and M. D. Verhagen, "Learning loss due to school closures during the COVID-19 pandemic," *Proc. Natl. Acad. Sci. U. S. A.*, vol. 118, no. 17, 2021, doi: 10.1073/PNAS.2022376118.

[5] E. Munawaroh, Y. Nurmalasari, U. N. Semarang, and U. N. Yogyakarta, "Student Resilience After Pandemic : Learning Loss Recovery 1 Student Resilience After Pandemic : Learning Loss Recovery," *J. Psikol. Edukasi dan Konseling*, vol. 1, no. 2, pp. 1–10, 2021.

[6] C. Alban Conto, S. Akseer, T. Dreesen, A. Kamei, S. Mizunoya, and A. Rigole, "Potential effects of COVID-19 school closures on foundational skills and Country responses for mitigating learning loss," *Int. J. Educ. Dev.*, vol. 87, no. May, p. 102434, 2021, doi: 10.1016/j.ijedudev.2021.102434.

[7] M. Kuhfeld and K. Lewis, "COVID-19-impacted School Years," no. 22, 2022.

[8] N. Angrist *et al.*, "Building back better to avert a learning catastrophe: Estimating learning loss from COVID-19 school shutdowns in Africa and facilitating short-term and long-term learning recovery," *Int. J. Educ. Dev.*, vol. 84, no. May, p. 102397, 2021, doi: 10.1016/j.ijedudev.2021.102397.

[9] C. Baumann *et al.*, "Effect of the COVID-19 outbreak and lockdown on mental health among post-secondary students in the Grand Est region of France: results of the PIMS-CoV19 study," *Health Qual. Life Outcomes*, vol. 19, no. 1, pp. 1–10, 2021, doi: 10.1186/s12955-021-01903-9.

[10] A. El-Osta *et al.*, "How is the COVID-19 lockdown impacting the mental health of parents of school-age children in the UK? A cross-sectional online survey," *BMJ Open*, vol. 11, no. 5, pp. 1–11, 2021, doi: 10.1136/bmjopen-2020-043397.

[11] N. Ozamiz-Etxebarria, N. Berasategi Santxo, N. Idoiaga Mondragon, and M. Dosil Santamaría, "The Psychological State of Teachers During the COVID-19 Crisis: The Challenge of Returning to Face-to-Face Teaching," *Front. Psychol.*, vol. 11, no. January, pp. 1–10, 2021, doi: 10.3389/fpsyg.2020.620718.

[12] S. Tang, M. Xiang, T. Cheung, and Y. T. Xiang, *Mental health and its correlates among children and adolescents during COVID-19 school closure: The importance of parent-child discussion*, vol. 279. Elsevier B.V., 2021.

[13] S. Fahruddin, "Penggunaan Metoda Difraksi Sinar X dalam Menganalisa Kandungan Mineral Pada Batuan Ultra Basa Kalimantan Selatan," *J. Fis. FLUX*, vol. 5 No. 2, no. 2, pp. 165 – 173, 2008.

[14] A. F. Virgilia Zephanya Bratanoto, Lita Latiana, "Penguatan Pembelajaran Jarak Jauh Anak Usia Dini Melalui Pendekatan STEAM Dan Pemberdayaan Keluarga," *Pascasarjana*, pp. 661–670, 2020.

[15] M. Indrawati, C. Prihadi, and A. Siantoro, "The Covid-19 Pandemic Impact on Children's Education in Disadvantaged and Rural Area Across Indonesia," *Int. J. Educ.*, vol. 8, no. 4, pp. 19–33, 2020, doi: 10.5121/ije.2020.8403.

[16] I. P. W. Adnyana, I. W. Darmadi, and D. Darsikin, "Penerapan Pembelajaran Konstruktivisme dengan Siklus Belajar Karplus untuk Meningkatkan Hasil Belajar Fisika Siswa Kelas VIIb3 SMP Negeri 14 Palu," *JPFT (Jurnal Pendidik. Fis. Tadulako Online)*, vol. 1, no. 2, p. 8, 2014, doi: 10.22487/j25805924.2013.v1.i2.2387.

[17] F. Ahmadi, S. Edi, B. A. A. Al-ghamdi, and D. Harjunowibowo, "Comparative Study of the Development of Android-Based Flipped Classroom Model between Jeddah and Indonesia," *Int. J. Adv. Sci. Eng. Inf. Technol.*, vol. 10, no. 2, pp. 542–547, 2020.

[18] F. Ahmadi, R. Rochmad, F. P. Lestari, and D. Harjunowibowo, "The Development of Mathematics Comic Containing Pancasila Values to Develop Character of Elementary School Students: A Case Study of Indonesia," *J. Innov. Educ. Cult. Res.*, vol. 2, no. 1, pp. 25–34, 2021, doi: 10.46843/jiecr.v2i1.20.

[19] N. Faturohman and A. Gunawan, "Tantangan Lembaga Pendidikan Dasar dalam Penyelenggaraan Pendidikan Pasca Pandemi COVID-19 di Kabupaten Serang," *Geneologi PAI J. Pendidik. Agama Islam*, vol. 8, no. 2, pp. 433–442, 2021.

[20] S. Dhawan, "Online Learning: A Panacea in the Time of COVID-19 Crisis," *J. Educ. Technol. Syst.*, vol. 49, no. 1, pp. 5–22, 2020, doi: 10.1177/0047239520934018.

[21] N. Adlina, "Inovasi Pembelajaran di Masa Pandemi COVID-19 dengan Pendekatan STEAM di Era Society 5.0," *J. Syntax Imp. J. Ilmu Sos. dan Pendidik.*, vol. 2, no. 6, p. 120, 2022, doi: 10.36418/syntax-imperatif.v2i6.134.

[22] D. Ratnasari, S. Sukarmin, S. Suparmi, and D. Harjunowibowo, "Analysis of science process skills of summative test items in physics of grade X in Surakarta," *J. Pendidik. IPA Indones.*, vol. 7, no. 1, pp. 34–40, 2018, doi: 10.15294/jpii.v7i1.10439.

[23] T. R. Kelley and J. G. Knowles, "A conceptual framework for integrated STEM education," *Int. J. STEM Educ.*, vol. 3, no. 1, 2016, doi: 10.1186/s40594-016-0046-z.

[24] H. O. K. Ahmed, "Strategic Future Directions for Developing STEM Education in Higher Education in Egypt as a Driver of Innovation Economy," *J. Educ. Pract.*, vol. 7, no. 8, pp. 127–145, 2016.
[25] N. H. Kang, "A review of the effect of integrated STEM or STEAM (science, technology, engineering, arts, and mathematics) education in South Korea," *Asia-Pacific Sci. Educ.*, vol. 5, no. 1, 2019, doi: 10.1186/s41029-019-0034-y.
[26] H. Jho, O. Hong, and J. Song, "An analysis of STEM/STEAM teacher education in Korea with a case study of two schools from a community of practice perspective," *Eurasia J. Math. Sci. Technol. Educ.*, vol. 12, no. 7, pp. 1843–1862, 2016, doi: 10.12973/eurasia.2016.1538a.
[27] S. Zubaidah, "STEAM (Science, Technology, Engineering, Arts, and Mathematics): Pembelajaran untuk Memberdayakan Keterampilan Abad ke-21," *Semin. Nas. Mat. dan Sains*, no. September, pp. 1–18, 2019.
[28] M. F. C. B. M. B. M. Horvathova, "Character education for the 21st century," *Cent. Curric. Redesign*, no. February, p. 25, 2015.
[29] R. Arch, "K a M Eha M Eha Sch O O Ls Re Se a Rc H & E Va Luati O N D I V I Si O N," pp. 1–25, 2010.
[30] M. Frydenberg and D. Andone, "Learning for 21 st Century Skills," *Int. Conf. Inf. Soc. i-Society 2011*, pp. 314–318, 2011, doi: 10.1109/i-society18435.2011.5978460.
[31] I. H. Mu'minah, "Studi Literatur: Pembelajaran Abad-21 Melalui Pendekatan Steam (Science, Technology, Engineering, Art, and Mathematics) Dalam Menyongsong Era Society 5.0," *Pros. Semin. Nas. Pendidik.*, vol. 3, pp. 584–594, 2021.
[32] F. Lalrinzuali and L. Hnamte, "The Four Pillars of Education and the Models of Teaching," *Mizoram Educ.*, vol. Vol. I, no. July, 2015.
[33] M. Bialik and C. Fadel, "Skills for the 21 st Century: What should students learn?," *Cent. Curric. Redesign*, vol. 3, no. 4, p. 29, 2015.
[34] T. Muthuprasad, S. Aiswarya, K. S. Aditya, and G. K. Jha, "Students' perception and preference for online education in India during COVID -19 pandemic," *Soc. Sci. Humanit. Open*, vol. 3, no. 1, p. 100101, 2021, doi: 10.1016/j.ssaho.2020.100101.
[35] S. Ghavifekr, Ahmad Zabidi Abd Razak Muhammad Faizal A. Ghani, Ng Yan Ran, Yao Meixi, and Zhang Tengyue, "ICT Integration In Education: Incorporation for Teaching & Learning Improvement," *Malaysian Online J. Educ. Technol.*, vol. 2, no. 2, pp. 24–54, 2014.
[36] A. Y. Wong and K. Daud, "ICT Competencies among School Teachers: A Review of Literature," *J. Educ. Learn.*, vol. 12, no. 3, pp. 376–381, 2018, doi: 10.11591/edulearn.v12i3.5579.
[37] B. A. Tarcha, B. P. P. Forte, E. J. Soares, and R. L. Thompson, "the Elasto-Viscoplastic-Time-Dependent Nature of Waxy Crude Oils," *Rev. Eng. Térmica*, vol. 13, no. 2, p. 16, 2014, doi: 10.5380/reterm.v13i2.62088.
[38] B. C. Luitel and N. K. Manandhar, "Education before , during and after pandemic : A proposal for STEAM education," *Educ. Commem.*, no. September, pp. 152–166, 2020.
[39] C. Gopo, "The role of technology in the 21st century education of learners," *Off. Res. J. Tagum City Div.*, vol. 18, no. 6, pp. 357–361, 2022.
[40] T. Hadinugrahaningsih, Y. Rahmawati, and A. Ridwan, "Developing 21st century skills in chemistry classrooms: Opportunities and challenges of STEAM integration," *AIP Conf. Proc.*, vol. 1868, no. August, 2017, doi: 10.1063/1.4995107.
[41] C. Liao, "From Interdisciplinary to Transdisciplinary: An Arts-Integrated Approach to STEAM Education," *Art Educ.*, vol. 69, no. 6, pp. 44–49, 2016, doi: 10.1080/00043125.2016.1224873.
[42] G. Hacques, J. Komar, M. Dicks, and L. Seifert, "Exploring to learn and learning to explore," *Psychol. Res.*, vol. 85, no. 4, pp. 1367–1379, 2021, doi: 10.1007/s00426-020-01352-x.
[43] M. E. Madden *et al.*, "Rethinking STEM education: An interdisciplinary STEAM

curriculum," *Procedia Comput. Sci.*, vol. 20, pp. 541–546, 2013, doi: 10.1016/j.procs.2013.09.316.
[44] M. Zaidi, B. Amiruddin, D. R. Magfiroh, and I. Savitri, "Analysis of The Application of The STEAM Approach to Learning In Indonesia : Contributions to Physics Education," vol. 1, no. 1, pp. 1–17, 2022.
[45] L. S. Nadelson, A. Seifert, A. J. Moll, and B. Coats, "An Integrated Approach to Teacher Professional Development in STEM," *J. STEM Educ.*, vol. 13, no. 2, pp. 69–84, 2012.
[46] A. E. Du Plessis, "The Lived Experience of Out-of-field STEM Teachers: a Quandary for Strategising Quality Teaching in STEM?," *Res. Sci. Educ.*, vol. 50, no. 4, pp. 1465–1499, 2020, doi: 10.1007/s11165-018-9740-9.
[47] I. S. Milara and M. Cortés, "Possibilities and challenges of STEAM pedagogies," no. March 2020, 2019, doi: 10.13140/RG.2.2.28652.31360.
[48] M. Tsakeni, "STEM Education Practical Work in Remote Classrooms: Prospects and Future Directions in the Post-Pandemic Era," *J. Cult. Values Educ.*, vol. 5, no. 1, pp. 144–167, 2022, doi: 10.46303/jcve.2022.11.
[49] M. S. Khine and S. Areepattamannil, *STEAM Education: Theory and Practice*, no. January. 2019.
[50] X. Wang, W. Xu, and L. Guo, "The status quo and ways of STEAM education promoting China's future social sustainable development," *Sustain.*, vol. 10, no. 12, 2018, doi: 10.3390/su10124417.
[51] B. P. Pant, B. C. Luitel, and I. M. Shrestha, "Incorporating STEAM pedagogia in teaching mathematics," *Proc. Eighth Int. Conf. to Rev. Res. Sci. Technol. Math. Educ.*, no. January, pp. 319–326, 2020.
[52] C. F. Quigley, D. Herro, and F. M. Jamil, "Developing a Conceptual Model of STEAM Teaching Practices," *Sch. Sci. Math.*, vol. 117, no. 1–2, pp. 1–12, 2017, doi: 10.1111/ssm.12201.
[53] J. S. T. Roberts, "Building Problem-Solving Skills Through STEAM," *ITEEA's 83rd Conf. Denver, CO - March 24-27, 2021*, no. June, pp. 8–13, 2020.
[54] L. A. Shepard, W. R. Penuel, and J. W. Pellegrino, "Using Learning and Motivation Theories to Coherently Link Formative Assessment, Grading Practices, and Large-Scale Assessment," *Educ. Meas. Issues Pract.*, vol. 37, no. 1, pp. 21–34, 2018, doi: 10.1111/emip.12189.
[55] R. A. Beghetto, "Creativity in classrooms," *Cambridge Handb. Creat. Second Ed.*, pp. 587–606, 2019, doi: 10.1017/9781316979839.029.
[56] A. ElSayary, "Teaching and assessing creativity in STEAM education," *ICSIT 2021 - 12th Int. Conf. Soc. Inf. Technol. Proc.*, no. Icsit, pp. 126–131, 2021.
[57] H. Long and J. A. Plucker, "Assessing creative thinking: Practical applications," *Routledge Int. Handb. Res. Teach. Think.*, no. June, pp. 315–329, 2015.
[58] L. Colucci, P. Burnard, C. Cooke, R. Davies, D. Gray, and J. Trowsdale, "Reviewing the potential and challenges of developing STEAM education through creative pedagogies for 21st learning: how can school curricula be broadened towards a more responsive, dynamic, and inclusive form of education?," *Br. Educ. Res. Assoc.*, no. August, pp. 1–105, 2017, doi: 10.13140/RG.2.2.22452.76161.
[59] Y. Kim and N. Park, "The effect of STEAM education on elementary school student's creativity improvement," *Commun. Comput. Inf. Sci.*, vol. 339 CCIS, pp. 115–121, 2012, doi: 10.1007/978-3-642-35264-5_16.
[60] Z. Zayyinah, E. Erman, Z. A. I. Supardi, E. Hariyono, and B. K. Prahani, "STEAM-Integrated Project Based Learning Models: Alternative to Improve 21st Century Skills," *Proc. Eighth Southeast Asia Des. Res. Second Sci. Technol. Educ. Arts, Cult. Humanit. Int. Conf. (SEADR-STEACH 2021)*, vol. 627, pp. 251–258, 2022, doi: 10.2991/assehr.k.211229.039.
[61] K. F. T. Lam, T. H. Wang, Y. S. Vun, and N. Ku, "Developing critical thinking in a STEAM

classroom," *CEUR Workshop Proc.*, vol. 2555, pp. 82–90, 2019.
[62] Q. Wang, "Using online shared workspaces to support group collaborative learning," *Comput. Educ.*, vol. 55, no. 3, pp. 1270–1276, 2010, doi: 10.1016/j.compedu.2010.05.023.
[63] C. Dede, "Comparing Frameworks for " 21 st Century Skills "," pp. 1–16, 2009.
[64] Y. C. Lu, W. S. Liu, T. T. Wu, F. E. Sandnes, and Y. P. Huang, "A Study of Problem Solving Using Blocks Vehicle in a STEAM Course for Lower Elementary Levels," *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 11937 LNCS, pp. 49–57, 2019, doi: 10.1007/978-3-030-35343-8_6.
[65] K. Ananiadou and M. Claro, "21st century skills and competences for new millennium learners in OECD countries," *OECD Educ. Work. Pap.*, no. 41, p. 33, 2009.
[66] E. van Laar, A. J. A. M. van Deursen, J. A. G. M. van Dijk, and J. de Haan, "Determinants of 21st-Century Skills and 21st-Century Digital Skills for Workers: A Systematic Literature Review," *SAGE Open*, vol. 10, no. 1, 2020, doi: 10.1177/2158244019900176.
[67] N. K. D. Suciari, L. Lbrohim, and H. Suwono, "The impact of PjBL integrated STEAM on students' communication skills and concept mastery in high school biology learning," *AIP Conf. Proc.*, vol. 2330, no. March, 2021, doi: 10.1063/5.0043395.
[68] J. Roche, L. Bell, I. Martin, F. Mc Loone, A. Mathieson, and F. Sommer, "Science Communication Through STEAM: Professional Development and Flipped Classrooms in the Digital Age," *Sci. Commun.*, vol. 43, no. 6, pp. 805–813, 2021, doi: 10.1177/10755470211038506.