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REVIEW

ICTs into mathematical instructions for meaningful teaching and learning

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Abstract: Mathematical illusions and concepts can be more easily visualized and understood with the help of information and communication technologies (ICT). On the contrary, ICT development in Nepali classrooms (from elementary school to university) moves glacially. This study examines the role of ICT tools in mathematics and their features and importance in promoting meaningful learning in mathematics. Based on the literature available, this study found that GeoGebra, Google SketchUp, and Microsoft Mathematics are excellent ICT tools for visualizing mathematical concepts, creating 3D models, and discovering solutions and graphical representations of more complex mathematical concepts and/or illusions. This study also demonstrates the importance of these ICT tools in promoting mathematics teaching and learning from elementary school to the university level. Incorporating the ICT tools mentioned above for teaching and learning mathematics has positively impacted students' achievement in mathematics.

Keywords: ICT, mathematics, teaching and learning, students' achievement

1 Introduction

As many developed countries enter the 'information age,' technological devices are used to modernize and improve living standards and education (Sophanak, 2018). Over the past decade, many schools in those countries have been using information and communication technology (ICT) to enhance and support their teaching and learning systems (Papadakis, 2021). In this scenario, comparing our context teaching and learning approach with those mentioned above, we found ourselves very behind in using ICT tools in our classrooms in Nepal. It has been argued that modern technology plays an indispensable role in teaching and learning mathematics (Ittigson & Zewe, 2003; Papadakis et al., 2018; Papadakis et al., 2021). Similarly, Sophanak (2018) offers that ICTs produce notable differences in teaching methodologies and approaches and learning activities inside the classroom. Likewise, Mikre (2011) states that ICT improves the educational environment, including collaborative, active, interactive, and creative (Katsaris & Vidakis, 2021). Nevertheless, in our experience, very few teachers can only integrate ICT in teaching and learning mathematics in our context. We felt that the less integration of ICT in our classroom might be the less awareness of mathematics teachers of ICT tools (Dahal et al., 2020; Dahal et al., 2022a; Dahal et al., 2022b).

Being a current mathematics teacher in one of the reputed schools in Kathmandu Valley, first author was also less known about those tools before a few years as our teaching and learning approach is highly conventional. "The usual way of teaching is still based on teacher presenting information to passive students (usually in the form of the so-called frontal instruction)" (Dhakal, 2018). In this scenario, we found that the less use of ICT tools in Nepali mathematics classrooms might be the less familiarity of mathematics teachers with ICT tools. We also experience that this teaching approach (conventional method) affects student performance, demotivates students in mathematics learning, and gives rise to math anxiety. According to recent surveys and research, many institutions have realized that feeling of dread affects math calculations and even harms working memory, and impacts mathematics performance (Justicia et al., 2017). This anxiety is spreading very widely in our context, and much more students are infected by this illness ranging from young to aged ones. Poudel (2015) argued that "School level students feel mathematics as a boring subject and harder one. Most students could not understand mathematics due to their perception of math". In this situation, a mathematics teacher can play a crucial role in motivating and engaging them in creative work by using different software like GeoGebra, SketchUp, Microsoft Mathematics, and many more to learn and understand mathematical concepts interestingly. This scenario of our context pushes us to seek a better

option to uplift mathematics education. As teachers, researchers, and practitioners, we feel the necessity of such research to give mathematics teachers and mathematics educators insight into the ICT tools and their benefits in teaching and learning mathematics. We try to claim that this study offers insight to the teachers and is equally essential for the mathematics learners of any level, which promotes their learning curiosity and creativity.

Likewise, while positing ourselves in the agendas, as a resident of Kathmandu valley, we were supposed to have much more sophisticated facilities in Nepal regarding teaching and learning procedures. We used to think that we had much more advanced teaching and learning technologies than other villages and cities. On the way to accomplishing a Master's degree in mathematics education, the first author realized that there is a lack of technology even in the schools of Kathmandu for teaching and learning. In this research, technology means the softcopy materials and software that can be integrated with teaching and learning mathematics to visualize the mathematical concepts.

Further, technology in institutions such as schools and colleges are less modern in terms of quality and functions and inadequate in numbers and generations, so the students cannot deal with modern learning processes and cannot withstand the challenges of a competitive world market (Qureshi & Qureshi, 2021). We also found many institutions where such technologies are available in the same sense. However, there is a lack of skillful human resources (*e.g.*, teachers), and the place where there is a skillful human resource is suffering from the lack of such tools. We experienced that the teaching and learning system is guided by the conventional approach (Dahal et al., 2019b), where the teacher and the textbooks are everything, and the teacher transfers knowledge from his/her head to the student's head just like transferring a data from one electronic device to another. In this situation, teaching and learning mathematics is only to get scores/grades in the exam without knowing concepts. Kathmandu is the capital city of Nepal, and even though it does not have satisfactory technology for teaching mathematics, what could be the condition of those villages and other rural areas?

We have experienced that in the Nepali context, the problem in the teaching and learning process often occurs. However, approaches for the development of technology also might be helpful to uplift the teaching and learning process as technology is the foremost requirement to upgrade the learning system in mathematics. In this sense, the first author feels that the mathematics teachers are less aware of and know significantly less about the mathematics-friendly teaching applications and tools in computers through which they can enhance the learners' understanding in a better way. So, this is our attempt to explore how the ICT tools have been used in teaching and learning mathematics in this article through which mathematics teachers and learners can enhance mathematical concepts, skills, and problem-solving strategies.

ICT "reform to forms of technology used to transmit, store, create, share or exchange information" (Dhakal, 2018). In addition to this, ICT refers to technologies that provide access to information through telecommunications. The technologies such as radio, television, satellite system, computer and network hardware and software and the equipment and services associated with those technologies, such as video conferencing and electronic mail, can be included in ICT (Iahad et al., 2012). It has been found that many newly discovered technologies practically affected the well-being of the teaching and learning process in recent years. In the field of mathematics, technology puts liveliness in its abstract nature. "Moreover, electronic devices can be used to achieve experiences that in everyday life and either inaccessible or accessible only due to time-consuming and often tedious work" (Dhakal, 2018).

ICT integration in teaching and learning mathematics provides a variety of instructional practices to the teacher and students in school education to engage them in the learning process (Poultsakis et al., 2021). For example, while teaching some opposite angles of a cyclic quadrilateral are supplementary, we (probably others) just draw the figure on the board and tell them that they are supplementary. We are also not against this approach, but students may understand better if a mathematics teacher can demonstrate it using ICT tools/applications from computers, laptops, mobile, and other devices. Furthermore, the students can also use the available ICT tools to design and solve their mathematical concepts at home/school. The use of computers and technology has become fundamental to the operation of organizations and society (Kroeker, 2010; Yonck, 2010). The ICT tools in education can transfer a massive amount of information in seconds, enabling humankind to advance in multiple ways. As a teacher and researchers, we are getting aware of ICT tools and their integration in mathematics classrooms, we felt a bit difficult in the beginning, but gradually we found this approach very practical and engaging while teaching mathematics in the classroom (Papadakis et al., 2016a, 2016b; Dahal et al., 2019).

Richardson (2011) found that ICT plays an essential role in helping teachers get updated information and improves teaching and learning activities in a modern way and better than before. The current scenario of Nepal shows that the education stakeholders and the policymakers are

in less favor of mathematics education as a compulsory subject in schools. This is because of increasing math anxiety and the number of failed and dropout students in mathematics because of traditional ways of teaching and learning mathematics in schools, colleges and universities. In this situation, ICT in mathematics can positively affect educational quality in Nepal due to its specification and functions' effect on students and the opportunities it suggests for coordinating distinction and individualization purposes.

Light (2009) found that the integration of ICT in classroom activities positively changes students' understanding and learning outcomes in terms of the ICT integration process in developing countries. Successful ICT integration into the mathematics curriculum is only possible if we know the existing software used by mathematics teachers (Dhakal, 2018; Tsoukala, 2021). "New technological applications such as GeoGebra, Google SketchUp, Sketch pad, etc., are becoming more useful to improve and enhance teaching and learning mathematics to visualize mathematical concepts" (Dahal et al., 2019a). Mathematics education without technology is boring, so it is necessary to integrate the ICT tools in mathematics classrooms. Fluck (2010) argued that the ICT should play a transformative role in education rather than integration into existing subject areas. A mathematics teacher should know the tools to support the teaching and learning process.

Guided by the research question, how do ICT tools such as GeoGebra, Microsoft Mathematics, and Google SketchUp support teachers and students in meaningful mathematics teaching and learning? This study explores the ICT tools such as GeoGebra, Microsoft Mathematics, and Google SketchUp and their use for meaningful teaching and learning of mathematics.

2 Methods

This study is designed to explore the tools and their applications in teaching and learning mathematics through ICT based on literature and our experiences in the journey as a student, teacher, teacher educator and educational researcher. To articulate this paper, we reviewed different dissertations, research papers, and journal articles (*e.g.*, Dhakal, 2018; Dahal et al., 2019a; Dahal et al., 2022a; Dahal et al., 2022b; Keong et al., 2005; Sarkar, 2015) to mention but not limited) which are similar to our research issue. In this sense, this study is a desk-based study (Javaid et al., 2022) where the researcher concludes with their ideas with the help of pre-existing literature. To begin, the researchers reviewed existing studies and developed a concept for this article based on the studies and experiences they encountered. In the second phase, the researcher documented the concepts while collecting the literature needed to support it.

3 Analysis and interpretations

This section of the study gives the framework based on pre-existing literature, which helps the researcher develop a concrete idea and helps to conclude. We have read more than forty articles exploring the ICT tools and their use in mathematics classrooms to develop the themes in this paper. While going through these papers, we found the most common and valuable software in teaching and learning mathematics are GeoGebra, SketchUp, and Microsoft Mathematics. We were also convinced of their use and positive impact on mathematics education. We, too, have found software like Matlab and Mathematica that contribute to mathematics learning, but they are less in use, and their features can be found in among the above three software. So, to support this research design, we have developed the themes like GeoGebra Enhances Students Ability in Visualizing Mathematics, SketchUp: An Eye to look Mathematics in 3D, Microsoft Mathematics helps explore the Algorithm of Mathematical Problem-solving Procedure and ICT Tools and Mathematics Education. We have collected the literature on the pre-existing studies under these themes, which work as a roadmap for concluding.

3.1 GeoGebra enhances students' ability in visualizing mathematics

In this theme, we first discuss the introduction of GeoGebra and its use and benefits in mathematics teaching-learning. While doing so, we shared our experience with its use and the works of literature that we have read. In this scenario, we experience that anybody can learn quickly and in an abbreviated time through visualization. For example, we can easily recite or understand a story from a movie, or any video or song quickly, but why does it take time to learn and understand the same story from the book? In the same sense, teaching mathematics through a conventional approach is not visualizing the learners' concepts in mathematics, which creates

misconceptions and illusions in learners' minds. "Today's guidelines for teaching mathematics indicate the key role of visualization techniques" (Majerek, 2014). The rapid change in the environment towards technology is remarkably high, and in this situation, the use of ICT in education is essential. Many software applications were created to build geometric construction and solve analytical and algebraic problems in response to this world's needs. In contrast, GeoGebra is found to be one of the best computer applications for visualizing mathematical concepts and illusions (Majerek, 2014).

Similarly, Dahal et al. (2019a) argued that "GeoGebra is an interactive geometry, algebra, statistics and calculus application designed to construct and illustrate the mathematical concepts". Markus Hohenwarter created it in 2001/2002 as a part of his master thesis. Later, he developed the software as a part of his PhD project in mathematics education with the help of the Austrian Academy of Science at the University of Salzburg in Austria (Majerek, 2014) and now has been translated to one hundred plus languages (Saha et al., 2010; Dahal et al., 2022b). It is amazingly effective and easy to use for all kinds of mathematics learners who want to visualize their mathematical ideas and solutions on the computer screen.

"GeoGebra is one of the recent instructional tools drawing much attention of researcher and mathematics educators for its potential to revolutionize mathematics teaching and learning" (Belghesis & Kamalludeen, 2018). This application has the features of Computer Algebra System, Dynamic Geometry software, and Spread-Sheets, all in a single integrated package (Hohenwarter et al., 2009). GeoGebra is free, open-source, dynamic software, making math education more student-centred (Saha et al., 2010). It can be downloaded from the official GeoGebra website at http://www.geogebra.org. This shows that students can engage themselves in the learning process by using this ICT tool.

When GeoGebra is used to teach math, it can help students see how the mathematical concepts change, making learning easier (Hodanbosi, 2001; Mohammad, 2004; Ahamad et al., 2010; Dahal et al., 2022b). According to Saha et al. (2010), there was a significant difference in the means of students' post-test scores in favour of the GeoGebra group. They discovered that computer-assisted instruction was superior to traditional instruction. They also discovered that computer-assisted instruction in the classroom is more effective than traditional instruction alone. Similarly, Henessy et al. (2001); Hannafin and Foshay (2008), and Ahmad Fuzi et al. (2010) also found that using math learning software had a positive effect, which helped students learn and understand more in their studies. Further, Belghesis and Kamalludeen (2018) conducted their study among Malaysian teachers through an online survey. They found a significant difference between users and non-users of GeoGebra in their intention to use GeoGebra in their mathematics classrooms.

All these views and Figure 1 and 2 below show that GeoGebra is a valuable and effective ICT tool (Software/ application) that can visualize the mathematical concepts and contribute to conceptual understanding.

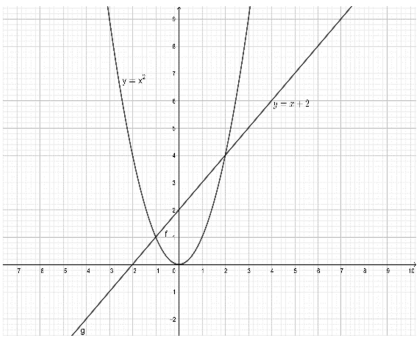

Figure 1 Parabola and Straight-Line

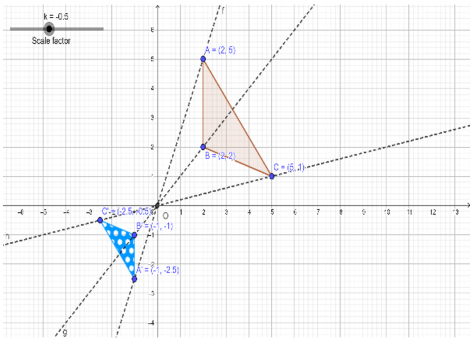

Figure 2 Enlargement [(0,0), 0.5]

3.2 SketchUp: An eye to look mathematics in 3D

This section in the research project has detailed information on SketchUp and its implication as a mathematical application that can promote visualizing mathematical illusions and concepts. We have also discussed its unique features and contribution to Mathematics learning with necessary literature and our experiences in it.

SketchUp (formerly Google SketchUp) is the three-dimensional (3D) design software that was first presented by Google in 2006 and was created to ease the design of buildings for the 3D city display on Google's satellite maps (Liveri et al., 2012). It is a modelling tool which can be used to create anything, from simple 3D shapes to complex models, thereby creating

creativity (Fischer et al., 2005). "One of the real advantages of the software is that it uses a collection of tools, which makes it suitable even for young ages since it does not set any limit to what children can achieve" (Liveri et al., 2012). In this scenario, if a mathematics teacher can integrate such an ICT tool into the mathematics classroom, the mathematics learning can be much better in conceptual understanding and motivating students toward the learning process. This software (SketchUp) is different from GeoGebra because it is more 3D design-oriented, whereas GeoGebra is more famous for visualizing the visual concepts of mathematics. Design houses, rooms, and cities are not accessible in GeoGebra, whereas SketchUp provides livelihood. One can quickly learn SketchUp by a tutor or with the help of YouTube videos and integrate or visualize the mathematical concepts in it creatively.

Visualizing any 2D and 3D models of mathematics can encourage the learner to create new ideas and innovations for their real-life situations. "SketchUp is a high functionality environment with a low threshold and a high ceiling; developing sophisticated models with SketchUp requires a nontrivial learning effort" (Liveri et al., 2012). This software/ application is directly beneficial for those interested in design. Such application in teaching and learning mathematics can enhance learners' capacity and creativity in real-life situations.

In our experiences, school students are creating massive misunderstandings in the section of geometry, 2D, and 3D objects and graphs, which are only visualized in their imaginations in the conventional classrooms. We found that a student who can easily find the volume of a solid in a verbal problem where the length, breadth, and height of a cuboid are given fails to recognize the dimensions and cannot find its volume when he/she is given a real object (cuboid). In our opinion, such impractical knowledge is the product of conventional pedagogical approaches. ICTs in mathematics classrooms can help visualize such verbal problems into 3D figures, which may give a better understanding, and learners may be familiar with real-life problems/situations. The aim of the integration of SketchUp in the mathematics classroom is to build a way of modelling a real-world phenomenon (Noss & Hoyles, 2006). The use of SketchUp in the mathematics curriculum can build a concrete idea, or it can set an image of the geometrical shapes of theoretical problems in textbooks in the learners' minds.

Figure 3 3D design of the building

The above views and Figure 3 show that Google SketchUp gives high proficiency in designing 3D objects. This software is a very effective ICT tool in teaching and learning mathematics, which can enhance learners' creativity and curiosity in mathematics.

3.3 Mathematical Problem-Solving procedure with Microsoft Mathematics

In this section, firstly, we introduced Microsoft Mathematics and its implication in Mathematical concepts. While doing so, we have shared our experiences and the benefits we can get from this application with the necessary literature. We, too, have shared the uniqueness of Microsoft Mathematics from GeoGebra and Google SketchUp in this section.

"Microsoft Mathematics program is free software made by Microsoft Corporation that has a symbolic computing system and work based on the mathematical expression" (Oktaviyanthi & Suprini, 2015). It has been using a very effective ICT tool in teaching and learning mathematics for a long time. This software is "appropriate to assist students in solving the problem of Linear Algebra, Statistics, Calculus and Trigonometry" (Oktaviyanthi & Suprini, 2015). Students use Microsoft Mathematics to see how graph functions work and solve problems involving the area under the curve or where the two curves meet. This ICT software is also used to visualize mathematical concepts, but it works differently than the previous two (GeoGebra and SketchUp), which we have mentioned above. This software measures the area under the curves and the higher Algebra and Calculus graphical representations. It helps in mathematical modelling, which is almost impossible in the above applications.

Many researchers have concluded that interactive technology, especially visualization tools, is an excellent way to get students interested in learning and make it more meaningful (Beynon

et al., 2010). Such a tool in ICT can develop an interactive visualization that helps the cognitive development of a learner. "Technology used for the educational purposes should be complemented with dynamic animations and flexible so that students can build an understanding in a better way" (Oktaviyanthi & Suprini, 2015). In this sense, Microsoft Mathematics somehow reduces the complexity of mathematics into learner-friendly objects. The researcher believes that anyone can learn much better by visualization (audio and visual) than by the lecture method. According to Amin (2013), ICT affects what students should learn, but it also plays a significant role in how the students should learn. In this scenario, Microsoft Mathematics' contribution is worth giving a conceptual understanding of higher mathematics.

Oktaviyanthi and Suprini (2015) conducted a mixed-method research design. They concluded that using Microsoft Math in the classroom is critical to helping students learn more efficiently than a traditional teaching approach. He also found that Microsoft Mathematics can improve students' interaction with computers to improve the representation of mathematical ideas and give a better understanding of mathematical content that conventional teaching may not obtain. Hogstad and Brekke (2010) argued that students must be able to see things move to comprehend and process information. The technology approach is based on doing, teaching, and seeing, leading to actions, beliefs, and learning products (Chiappini & Bottino, 2012). To deal with "reasoning building, exploring knowledge, solving problems and generating new ideas" (Oktaviyanthi & Supriani, 2015), technology can be considered a boon. Along with these, technology invests a lot in visualizing mathematical concepts with good clarity of students' knowledge in mathematics. Multimedia makes a learner creative as it includes instruction through which one can gain knowledge with various activities like communicating with information, involving in more than one way to present something and a reminder of how it can be done (Oktaviyanthi & Suprini, 2015).

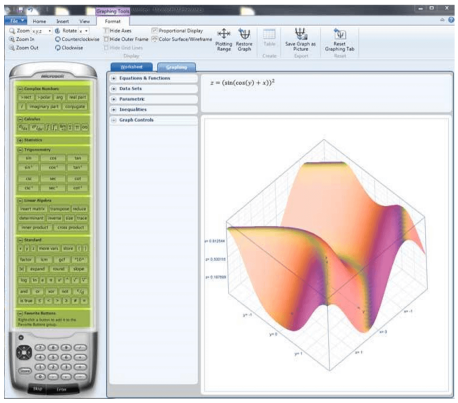

Figure 4 Visual of trigonometric concepts

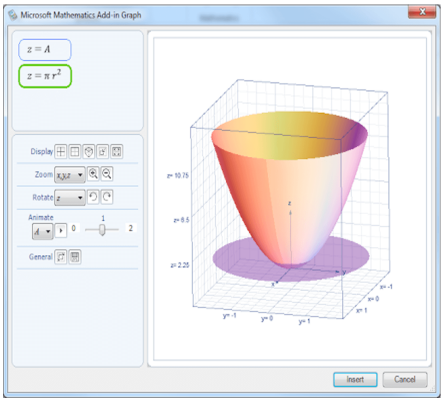

Figure 5 2D and 3D visual

The above views and Figure 4 and 5 show that Microsoft Mathematics software is incomparable to higher mathematics software. This application can visualize the very abstract and symbolic representations of higher Algebra and its functions in understandable images and solve the problems in Calculus which is found as a living calculator in mathematics education.

3.4 ICT tools and mathematics education

In this section, we have emphasized the use and importance of ICT tools in mathematics education. In the present context, the use of ICT in the educational field is worthwhile. During the research period, the entire world is under the threat of Corona Virus (COVID- 19), and the whole country is under lockdown. In that situation, many universities and institutions conduct their classes online, and it is only possible because of ICT. "ICT increases the flexibility of delivery of education so that the learner can assess knowledge anytime and from anywhere" (Amin, 2013); so many other students can get access to education by using ICT tools. In other words, we can say that ICT eliminates geographical barriers as learners can log in from any places (Cross & Adam, 2007). In this research, we have discussed some ICT tools or computer applications which can be integrated into mathematics classrooms. Daud and Khalid (2014) argued that the use of ICT in education is becoming more crucial as it enables the development of a more initiative-taking teaching and learning environment. Next, according to Keong et al. (2005), 89.5% of mathematics educators use basic ICT applications in their teaching. "These basic applications include training software, visual and graphics and online demonstrations" (Zakaria & Khalid, 2016) as a teaching aid in mathematics. This shows that ICT has become an

inseparable organ of mathematics in the present era.

If we need to talk about mathematics in our context, from the school level to the University level, we can find its content full of dilemmas and illusions. Students are making misconceptions about the concepts of Mathematics like the interpretations of graphs of trigonometry, graphs of diverse types of equations, geometrical interpretations, etc. ICT plays a crucial role in realizing such concepts and ideas in such situations. In this context, ICT helps in providing a catalyst for rethinking teaching practice (Flecknoe, 2002). Students can reflect on themselves in their creations and change themselves according to their needs and curiosity. "The application of ICT can help educators obtain resources from outside their networks, thus enabling them to transform the teaching and learning process" (Zakaria & Khalid, 2016). In this sense, we found ICT as a tool to see mathematics in multiple ways, like theories from the texts and visualization using computer applications.

We have experienced that ICT can be an agent in transforming our lecture-based classrooms into activity-based classrooms. "It was found that the benefits of applying ICT in mathematics teaching include attracting students' interest in learning mathematics; improving students' performance; encouraging lifelong learning; enabling positive interactive relationships; and supporting constructivist learning" (Zakaria & Khalid, 2016). Similarly, "If technologies are used appropriately, it can accelerate the students' effective learning" (Dahal et al., 2019a). In this sense, we found ICT as a shifting agent from the conventional classroom to the modern ICT-based classrooms in Mathematics education. In our opinion, the present scenario of a typical family or a student who wants to upgrade oneself towards a comfortable and more accessible lifestyle with the help of technologies in different ways like telecommunications, transportation, and many more. In this situation, as a mathematics teacher and a student in the same field, we found that if a learner can integrate the ICT tools into his/ her Mathematics learning, it can bring a considerable change in the creativity and understanding of mathematical concepts quickly.

Such software can make the education system more effective and motivate students to learn mathematics (Dahal et al., 2019a). Students can show their creativity and uniqueness in solving and designing mathematical concepts and ideas using it. Sometimes, they can perform better than they have been taught in the classrooms and invent something new for the world. In this sense, we have concluded that ICTs can create a better platform for a mathematics learner through which they can show his/ her talent in a multiple perspective as per their competency area.

4 Conclusion

From the above literature and discussion, we try to conclude that the ICT tools such as GeoGebra, SketchUp, and Microsoft Mathematics help develop a conceptual understanding of mathematics in school through visualization. After going through the many articles related to ICT integration in mathematics education, we found that ICT makes 21^{st}-century mathematics classrooms more engaging and creative. We also conclude that if a mathematics teacher can integrate the ICT tools in their classroom for learning and teaching activities, it can enhance the learner's ability. Research has articulated that ICT tools such as GeoGebra, SketchUp, and Microsoft Mathematics have a positive impact on teaching and learning mathematics (Majerek, 2014; Saha et al., 2010; Belghesi & Kamalludeen, 2018; Kurtulus & Uygan, 2010; Dhakal, 2018; Oktavigyanthi & Supriani, 2015; Dahal et al., 2019a; 2020; 2022a; 2022b). They also conclude that they have a significant difference in the students' performance and achievement by using these ICT tools and found as a powerful agent in the better attainment of mathematics teaching and learning. We have also concluded that using ICT applications in mathematics classrooms make the teaching and learning procedures easy. However, it can give a conceptual understanding and make the learner creative and curious about mathematics.

5 Implication

This study might be helpful for all the stakeholders advocating for incorporating ICTs applications in teaching and learning mathematics. It is beneficial for the practitioner teacher of mathematics to identify the ICT tools they can integrate into their mathematics classroom to teach and learn mathematics better. This study is also meaningful for the mathematics learner who wants to explore something new and can give a better platform to visualize their mathematical concepts and issues. All the software we have mentioned above can be used in mathematics visualization, but they have significant differences. GeoGebra visualizes simple mathematical concepts like graphs, functions, and mathematical illusions; however, its versions

are upgrading day by day and are currently found in quite advanced form, while SketchUp is mainly used in designing the home decors. SketchUp can be widely used in the mensuration topic. Students can create their room, house, and other real-life artefacts and easily find their area, volume, and other necessary ideas. Microsoft mathematics can be used for simple to complex mathematical concepts. Currently, this software is incredibly famous in higher studies but can be used in school mathematics. In this sense, this study is meaningful for all types of learners in mathematics. They can use any mathematical tool as per their need, interest, and software complexity.

Conflicts of interest

The authors declare that they have no conflict of interest.

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