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Research trends in dynamic geometry software: A content analysis from 2005 to 2021

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Abstract

Dynamic geometry software (DGS), especially GeoGebra, have been used in mathematics lessons around the world since it enables a dynamic learning environment. To date, there exist so many published researches about DGS, which leads to the need for meaningful organisation. This study aims to give a broad picture about researches related to DGS. For this reason, 210 articles accessed from the Web of Science database were analysed in terms of their purpose, research design, sample level, sample size, data collection tools and data analysing methods by using the content analysis method. According to the findings, for each section the most frequently used ones were as follows: 'the effect of DGS on something' as a purpose, qualitative method as a research design, high school students as a sample level, 101–300 intervals as a sample size, documents and achievement tests as instruments and descriptive analysis for quantitative and qualitative studies. These results can help researchers to see the past trends in DGS and conduct new studies.

Keywords: Dynamic geometry software, DGS, GeoGebra, content analysis, mathematics education

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1. Introduction

The usage of technology in both teaching and learning mathematics is increasing. Since multiple representations in mathematics have an important role in understanding concepts more effectively, the physical models or concrete manipulatives were transformed to computers in order to make their access easy. So, students and teachers from all around the world can reach these manipulatives and make practice more than by using limited number of models. Besides, computerised physical models give teachers the opportunity to integrate them in their lessons to create a more effective learning environment for their students (Bouck & Flanagan, 2009; Van de Walle et al., 2007). However, the need for constructing more specific models with respect to their own lesson subject or mathematical problems has come to light, which leads them to use dynamic geometry software (DGS) programmes in classrooms. DGS programmes enable us to make constructions by using simple tools and moving them by dragging points or slides (Young, 2017). Thus, teachers can use their own constructions in their lessons to conceptualise problems and to show different examples with the help of its dynamic features. Moreover, dynamic geometry software programmes enable students to visualise concepts, build relationships, discover patterns, generalise them, make geometrical proofs and develop their skills like problem-solving and creative thinking (Acikgul, 2017; Chan, 2014; Samur, 2015).

Considering the significance of DGS with its contributions to education, GeoGebra is the most popular one among the others, like Cabri 3D, Geometer's Sketchpad and Geometric Supporter, because GeoGebra is an open source software and it includes a combination of arithmetic, geometry, algebra and calculus systems. Also, it enables us to connect other users from all over the world, access others' materials and download available files (Hohenwarter & Fuchs, 2004). As a result, so many studies, theses and researches involve GeoGebra as the most commonly used DGS in mathematics education (Akyuz, 2016). For example, there are some studies that look at the effects of using GeoGebra on students' success, their mathematics attitudes (Arbain & Shukor, 2015; Saha et al., 2010) or their skills like problems-solving (Jacinto & Carreira, 2017; Koyuncu et al., 2015; Murni et al., 2017) and some studies also provide an example of how to use GeoGebra in teaching specific subjects in mathematics (Breda & Santos, 2016; Fonseca & Franchi, 2016; Nobre et al., 2016; Poon, 2018; Takaci et al., 2015). This means that there are studies on GeoGebra in the literature conducted by different methods, samples and procedures. Therefore, due to the mass of published works on DGS, there is a need to organise them in a meaningful way. Similarly, in the field of mathematics education and technology-supported mathematics education, there are some studies that have examined articles available in various databases with different time intervals and categories (Baki et al., 2011; Ciltas et al., 2010; Chan, 2014; Tatar et al., 2014; Ulutas & Ubuz, 2008; Young, 2017).

Baki et al. (2011) analysed 284 graduate theses in the field of mathematics education between the years 1998 and 2007 retrieved from online databases of the Higher Education Council and Proquest and the library of each university. According to the results of this study, teaching mathematics as a research topic, experimental design as a research design, questionnaires and achievement tests as data collection tools and 6th, 7th and 8th grade students as participants are the most preferable ones.

In mathematics education, the study conducted by Ulutas and Ubuz (2008) analysed 129 articles between the years 2000 and 2006. These articles were published in *Eurasian Journal of Educational Research*, *Hacettepe University Journal of Education*, *Elementary Education Online* and *Education and Science Journal*. The analyses indicate that most studies have samples of the education faculties of universities in the Central Anatolia Region and members are elementary students or preservice teachers. In addition to these, the most common research designs are experimental and quantitative in nature using tests and questionnaires; the most common research topics are numbers and geometry topics and their cognitive–affective domains.

Ciltas et al. (2010) analysed 359 articles related to mathematics education in the years from 1987 to 2009. These articles were obtained from 32 different journals, which were national (27) and indexed in Web of Science [Social Sciences Citation Index (SSCI)] (5). The results of the study state that most of the studies used quantitative research as the research design, learning activities, studies as research topic and frequency as the data analysis method. Also, more than one data collection instrument was used in most studies.

For technology-enhanced mathematics instruction, Young (2017) conducted a second-order meta-analysis of 19 researches that were obtained from the databases of ERIC, PsycINFO, ProQuest Dissertations and Theses Full-text and Academic Search Complete between the years 1985 and 2015. The aim of the study was to determine the cumulative effects of technology on student achievement with a summary of 30 years of research. As a conclusion, this study provides that technology-enhanced instruction has a moderate cumulative effect on student achievement. Also, it concluded that technology component and study quality are important contributors effecting size variation.

In addition to the content analyses on mathematics education, Tatar et al. (2014) conducted a study to analyse 105 graduate theses about technology-supported mathematics education in Turkey. According to the study, mathematics education among the categories of mathematics, mathematics education and technology as keywords, algebra as a subject, computer as a technology device and 6th, 7th and 8th grade students as a sample were used more frequently in the studies. Also, most of the studies preferred to use the mixed research methods, quantitative and qualitative studies, respectively. The most commonly used data collection instrument is achievement tests; the most commonly used data analyses methods are mean/standard deviation for quantitative data and descriptive analysis for qualitative data. Furthermore, it was indicated that experimental groups who had technology-supported education have higher scores in achievement, attitude towards mathematics, interest in mathematics, motivation for mathematics and retention of learning.

Chan (2014) analysed nine eligible articles on DGS-based instruction from 587 studies from 2001 to 2013 by using the databases of ERIC, JSTOR, ProQuest, PsycINFO and SwetsWise. The purpose of this meta-analysis was to determine the effects of DGS-based instruction on students' mathematics achievement in K–12 education as regards the traditional pencil-and-ruler instruction. So, the results of the study demonstrate that DGS-based instruction has a positive and large affect (d = +1.02) on mathematics achievement.

Joung and Byun (2021) analysed 23 digital mathematics games used in mathematics education in terms of NCTM (National Council of Teachers of Mathematics) content and process standards, which could help teachers to choose the appropriate games for their lessons. In this study, the number of puzzle games is more than the other types, which are categorised as action, strategy and others. Also, it was found that most of the games are related to the number and operations among the contents of number and operations, algebra, geometry and measurement and data analysis and probability. The most frequently used process standards to least the ones are stated, respectively, as problem-solving, connection, reasoning proof and representation.

As seen from these studies, researches should be analysed and arranged regularly in order to lead researchers to see the big picture in a specific area. Trends in a specific area can be determined by analysing the contents of the studies. So, by considering the contributions of identified trends, future researches can be developed. In this research, the content analysis method was used to analyse the studies on DGS published in Web of Science and indexes such as Social Science Citation Index (SSCI), Science Citation Index Expanded (SCI) and Emerging Sources Citation Index (ESCI). Therefore, the aim of the study is to determine the trends in DGS, especially in mathematics education. The research questions addressed by this study are as follows:

1. Which research purposes are included in the articles until 2018?
2. Which research designs have been used in the articles until 2018?
3. With which samples have been studied in the articles until 2018?
4. With which sample sizes have been studied in the articles until 2018?
5. Which data collection tools have been used in the articles until 2018?
6. Which data analysing methods have been used in the articles until 2018?

2. Methods

2.1. Research design

Content analysis is defined as 'a systematic, replicable technique for compressing many words of text into fewer content categories based on explicit rules of coding' (Stemler, 2000). In this study, this method was used to analyse the articles related to DGS accessed from the Web of Science database. Since the aim of the research is to identify the trends in studies regarding DGS, it is appropriate to use this method which enables to classify data by specific themes and concepts (Frankel et al., 2012). Thus, the systematically organised and categorised data can help the reader to understand the evaluations and interpretations about the trends in this specific area (Gay et al., 2012).

2.2. Sample

The population of the study includes DGS articles that were published in the journals and indexed in Web of Science. The reason why this database was chosen is because it includes qualitative journals in academics and it has enough related journals for content analysis. So, the population was restricted to this database. From this population, the sample was selected by using the convenience sampling method since it allows using already available sample based on a specific interest and characteristic features of the study (Frankel et al., 2012). As a result, 210 English articles about DGS published in more than 50 different journals in the indexes of SSCI, SCI and ESCI from 2005 to mid-2021 were accessed for a sample of this research. The keywords 'GeoGebra' and 'dynamic geometry software' were used. The names of the articles analysed are presented in Appendix 1.

2.3. Data collection tools

In this study, the modified type of the combination of two forms, which are the Educational Technology Publication Classification Form developed by Goktas et al. (2012) and the Paper Classification Form (PCF) developed by Sozbilir et al. (2012), were used as data collection tools. In order to categorise the contents of the articles, the original version of these forms was changed with respect to the purpose of this study. At the end of the adaptation process of the forms, the modified version was used for the present study. This form consists of seven components, which are (1) identification, (2) the purpose of the paper, (3) research design/methods, (4) sample level, (5) sample size, (6) data collection tools and (7) data analysis methods used in the papers. For the purpose of the paper, categories were *created according to the articles considered after reading each of them. Therefore, in addition to the identification of the formal structure of the articles in terms of research design, data collection tools, sampling and sample size and data analysis methods, the purpose of DGS was added as a component in the modified version of the form in order to examine the articles in a more contextual way.*

2.4. Data analyzes

In the context of the study, data gathered by the content analysis method of the articles were analysed by using descriptive statistics. With the help of the Excel programme, data frequencies and percentage tables were formed and the results were presented as graphics for each research question.

3. Results

The findings obtained through the analysis of the articles related to DGS indexed by SSCI, SCI and ESCI in the Web of Science database are presented under six sections. The sections parallel to the research questions are as follows: purposes, research design, sample level, sample size, data collection tools and data analysing methods. Under each section, the findings are represented by tables or/and figures.

3.1. Purposes

The studies identified are classified under four main categories: 'the effect of DGS', 'the usage of DGS', 'technical development of DGS' and 'others'.

- *The effect of DGS* refers to the studies that examine the effect of DGS on different outcomes. In this sense, the studies emphasise participants' achievement in mathematics or learning a specific mathematical concept with the help of DGS or understanding the mathematical concepts by using it; these have been categorised as the effect of DGS on achievement /learning/understanding. The studies with regard to the impact of DGS on participants' skills like connection and problem-solving have been analysed under the effect of DGS on skills in terms of their types. Also, the studies addressing the impact of DGS on participants' views about something like DGS integration in lessons or their attitudes towards something like mathematics have been categorised as the effect of DGS on attitudes/views towards/about something. The studies considering the effect of DGS on participants' cognitive processes and their competence on something like mathematics have been categorised under the effect of DGS on cognitive processes and the effect of DGS on competence.
- *Sample applications of DGS* refer to the studies using DGS for different purposes. The studies showing an example about how to use DGS for teaching specific concepts have been categorised as the sample applications of DGS for teaching the concept. Also, some studies demonstrating an example about how to make a construction of a specific concept in the DGS environment or how to visualise/illustrate the concept by using DGS have been categorised as the sample applications of DGS for constructing/visualising/illustrating a specific concept.
- *Technical development of DGS* refers to the studies about improving a tool/programme in DGS or technical features.
- *Others* refer to the studies not sorted by these categories and not having common features.

Table 1 indicates the distribution of the articles' purposes based on the classification regarding these categories. Figure 1 shows the distribution of categories as proportions. In Figure 1, it can be seen that 'the effect of DGS' consists of 58.8% of the identified studies and 'the usage of DGS' consists of 30.8% of them, 'technical development of DGS' consists of 6.6% of them and 'others' consists of 3.8% of them.

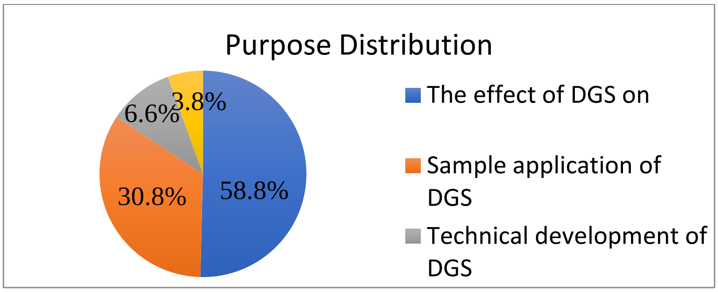

Figure 1. Distribution of the articles on DGS according to their purposes

In Table 1, it can be seen that the majority of researches are about the effect of DGS on achievement/learning/understanding (*f* = 54) among the categories under the effect of DGS. However, the effect of DGS' cognitive processes (*f* = 10) is the least preferred purpose outcome among them. Also, spatial/visualisation skills (*f* = 8), reasoning/argumentation skills (*f* = 8) and teaching skills of technology-integrated lessons (*f* = 8) are used in the studies examined more than the other skills. Besides, constructing/visualising/illustrating the concept (*f* = 47) is more frequently used rather than teaching the concept (*f* = 28) in the sample application of DGS.

Table 1. Distribution of the articles on DGS according to their purposes

Themes	Categories	Sub-categories	*f*
The effect of DGS	Achievement/learning/understanding		54
		Spatial/visualisation skills	8
		Reasoning/argumentation skills	8
		Teaching skills of technology-integrated lessons	8
		Problem-solving skills	7
		Connection skills	5
		Proofing skills	4
		Questioning skills	3
		Creativity skills	2
		Communication skills	1
	Cognitive processes	Advanced mathematical thinking	5
		Geometric cognitive growth	5
	Attitudes /views	Integration DGS	9
		Using DGS	8
		Mathematics	3
	Competence	Mathematical competence	5
		Mathematics self-efficacy	4
		Computer self-efficacy	2
	Motivation		2
Sample application of DGS	For constructing/visualising/illustrating the concept		47
	For teaching the concept		28

Technical development of DGS	16
Others	9
Total	243

3.2. Research design

The research designs used in the examined articles are given in Table 2. Also, Figure 2 shows the distribution of the research designs in terms of qualitative, quantitative and mixed methods. So, it can be said that the most preferred method is qualitative method (60.3%) among them.

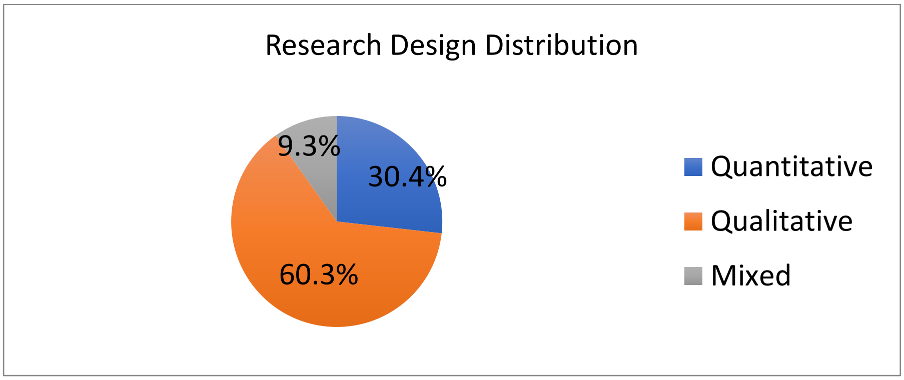

Figure 2. Distribution of the articles on DGS according to their research designs

In Table 2, it can be seen that the quasi-experiment (47) is the most preferred design among the quantitative methods; the case study (56) and the concept analysis (43) are the most preferred designs among the qualitative methods; and embedded design (9) is the most preferred among the mixed methods. Also, it can be seen that the non-experimental designs [descriptive (2), comparison (2) and correlation (2)] are not used in studies as much as the experimental designs [weak (7), true (2) and quasi (47) experiments].

Table 2. Distribution of the articles on DGS according to their research designs

Research design			Frequency
Quantitative	Experimental	Quasi-experimental	47
		Weak experimental	7
		True experimental	2
	Non-experimental	Descriptive	2
		Comparison	2
		Correlation	2
Qualitative	Interactive	Case study	56
		Design-based research	6
		Action research	3
		Phenomenology	2
		Grounded theory	2
	Non-interactive	Concept Analysis	43

		Review/meta-analysis	11
Mixed	Embedded		9
	Exploratory		6
	Explanatory		2
	Triangulation		2
Total			204

3.3. Sample level

The frequencies and percentages of sample levels used in the identified studies are given Table 3 and its demonstration with a pie chart is shown in Figure 3. It can be seen that the most frequently used sample level is high school students (*f* = 38, 24.8%). This is followed by the pre-service mathematics teachers (*f* = 37, 24.2%), other university students (*f* = 26, 17%), middle school students (*f* = 21, 13.7%) and mathematics teachers (*f* = 19, 12.4%). In addition to these, master/PhD students (*f* = 6, 3.9%), elementary school students (*f* = 6, 2.6%) and others (*f* = 2, 1.3%) are the least frequently used samples in the studies.

Table 3. Distribution of the articles on DGS according to their sample level

Sample level	Frequency *f*	Percentages %
High school students (9–12)	38	24.8
Pre-service mathematics teachers	37	24.2
Other university students	26	17.0
Middle school students (6–8)	21	13.7
Mathematics teachers	19	12.4
Master/PhD students	6	3.9
Elementary school students (1–5)	4	2.6
Others/researcher/trainer/mathematician	2	1.3
Total	153	100

3.4. Sample size

The sample sizes used in the studies are classified into intervals according to the PCF selected. Table 4 shows the frequencies and percentages of the sample size intervals used. Thus, it can be seen that the majority of the studies preferred to use 101–300 intervals (f=44, 32.6%) as a sample size. After this, 11–30 intervals (*f* = 31, 23%), 31–1000 intervals (*f* = 31, 23%) and 1–10 intervals (*f* = 25, 18.5%) were mostly used ones. Also, the table and figure show that the studies using greater than 300 participants are not common [301–1000 interval (*f* = 3, 2.2%), greater than 1000 (*f* = 1, 0.7%)].

Table 4. Distribution of the articles on DGS according to their sample sizes

Sample size	Frequency *f*	Percentage %
1–10 interval	25	18.5
11–30 interval	31	23.0
31–100 interval	31	23.0
101–300 interval	44	32.6
301–1000 interval	3	2.2
Greater than 1000	1	0.7
Total	135	100

3.5. Data collection tools

The frequencies and percentages of the data collection tools used in the studies examined are shown in Figure 3 as a graphical distribution. So, it can be seen that the most preferred tools are documents (*f* = 63, 22.4%) and achievement tests (*f* = 63, 22.4%), which are followed by observations (*f* = 57, 20.2%), interviews (*f* = 47, 16.7%), questionnaires (*f* = 37, 13.2%) and other tests (*f* = 14, 5%).

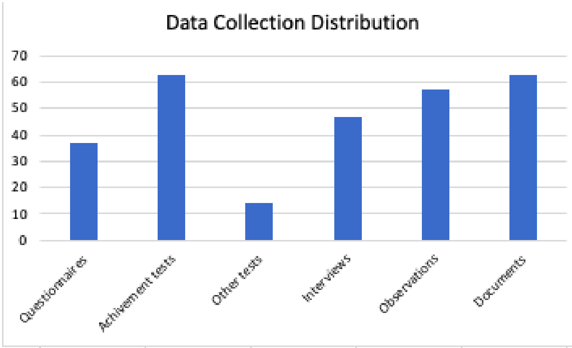

Figure 3. Distribution of the articles on DGS according to their data collection tools

From Table 5, revealing the data collection tools in more detail, it can be seen that studies preferred to use Likert type (10%) more than open-ended (3.2%) questionnaires; multiple choice (14.2%) more than open ended (8.2%) in achievement test; semi-structured (14.2%) more than structured (2.5%) in interviews; with participant (16.4%) more than focus group (2.1%) and without participant (1.8%) in observations.

Table 5. Distribution of the articles on DGS according to their data collection tools

Data collection tools		Frequency *f*	Percentage %
Questionnaire	Open-ended	9	3.2
	Likert	28	10.0
Achievement test	Open-ended	23	8.2
	Multiple choice	40	14.2
Other tests	Attitude test	3	1.1
	Skill test	8	2.8
	Self-efficiency test	3	1.1
Interview	Structured	7	2.5
	Semi-structured	40	14.2
Observation	Focus group	6	2.1
	With participant	46	16.4
	Without participant	5	1.8
Documents		63	22.4
Total		281	100

3.6. Data analysing methods

Table 6 demonstrates the frequencies and percentages of the data analysing methods used in the studies identified. As can be seen, descriptive analysis (23.5%), *t*-test (11.6%) and analysis of variance (ANOVA)/analysis of covariance (ANCOVA) (7.1%) from inferential statistics are the most frequently used methods in quantitative studies. Besides, the usage of the descriptive analysis (22.3%) is more than the usage of the content analysis (13.2%) and document analysis (12.6%) in qualitative studies.

Table 6. Distribution of the articles on DGS according to their data analyzing methods

Data analysing method			Frequency *f*	Percentage %
Quantitative	Descriptive	Frequency/Percentage	32	10.3
		Mean/SD	41	13.2
	Inferential	*t*-test	36	11.6
		ANOVA/ANCOVA	22	7.1
		Correlation	4	1.3
		Multivariate analysis of variance /Multivariate analysis of covariance	6	2.0
		Factor analyse	2	0.6
		Regression	1	0.3
		Non-parametric tests	17	5.5
Qualitative	Descriptive Analysis		69	22.3
	Content analysis		41	13.2
	Document analysis		39	12.6
Total			310	100

4. Discussion and conclusion

In this study, it has been aimed to examine the trends in researches on Dynamic Geometry Software, especially on GeoGebra. So, 210 articles with regard to this subject matter accessed from Web of Science and indexed in SSCI, SCI and ESCI were analysed.

The first research question of the present study is regarding the identification of the research purposes in the examined studies. At the end of the content analysis, the findings indicate that observing 'the effect of DGS on something' is the most preferred purpose and its effect on achievement/learning/understanding is most frequently used among others. This may result from the fact that by the increasing the popularity of DGS, the uncertainty of the DGS effect on learning mathematical concepts and the curiosity, whether it aroused students success on mathematics, lead researchers to test, observe and analyse its effects on achievement (Young, 2017). In addition, the reason why 'the usage of DGS' is the second category including the majority of studies may be that its integration to lessons have become a problem among educators and teachers, leading them to give some construction and lesson examples.

The second research question of the present study is about the examination of the distribution of the research designs used in the identified articles. The results indicating that the most preferred method is qualitative method (60.3%) among them contradicted the results of other studies. The results of the studies conducted by Baki et al. (2011) and Ulutas et al. (2008) show that the most common design in the mathematics education is the experimental design. Also, Ciltas et al. (2010) report that the quantitative design is the most frequently used design in mathematics education. Furthermore, according to the results of Tatar et al.'s (2014) study, the mixed method is the most common in the technology-supported mathematics education. This contradiction may result from the lack of technological pedagogical content knowledge about the usage of DGS on teaching mathematical concepts as a material, since the present study shows that the concept analysis and case study are the most frequently used designs. How to make constructions of some mathematical concepts by using DGS and to teach concepts by using it may lead the studies to use qualitative methods to show some examples and sample instructions. On the other hand, it was observed that experimental study was used more than the non-experimental design among the quantitative studies in the present study. So, this result is parallel to the studies addressing the experimental design as the most common method (Baki et al., 2011; Ulutas & Ubuz, 2008). It can be concluded that the tendency to observe the effect of DGS on something (achievement, skills etc.) may result in using control and experimental groups in the studies with the experimental design.

According to the third research question relating to the examination of the sample level distribution, the results indicate that high school students, pre-service mathematics teachers and other university students are the most frequently used samples in the studies identified. This may result from the convenient sampling which enables researchers to use their own students (pre-service math teachers and other undergraduate students). Also, the reason for using the high school students mostly may be related to the nature of DGS and mathematics. Calculus and middle school mathematics curriculum objectives may be more appropriate to use DGS than others, and also the high school students can learn DGS easier than elementary school students. Like the results of the present study, other studies in mathematics education commonly prefer to use middle-grade students as a sample (Baki et al., 2011; Tatar et al., 2014). Moreover, Ulutas and Ubuz (2008) state that the most frequently used participants are pre-service teachers or elementary students. At this point, although this study supports the results of the present study for pre-service teachers, it contradicts the present study's findings which indicate that the elementary students are among the least frequently used samples. Thus, it can be suggested that elementary students can be preferred as much as university and middle-grade students.

Based on the findings of the present study related to the fourth question, 101–300 intervals is the most common among them as a sample size. These findings support the results of the studies conducted by Ciltas et al. (2010) and Tatar et al. (2014). Besides, this may be a result of the fact that the experimental studies, especially quasi-experimental design, require mostly two groups with more than 30 to compare them in some specific dimension.

The fifth question is related to the exploration of the distribution of the data collection tools used in examined studies. As the findings indicated, documents and achievement tests are the most preferred instruments. With regard to achievement test, this result can be supported by the result of Tatar et al.'s (2014) study in which achievement test was found to be the most common tool. Moreover, other studies conducted by Baki et al. (2011), Ciltas et al. (2010) and Ulutaş and Ubuz (2008) determined that the achievement test and questionnaires are the most frequently used instruments in mathematics education. The reason of using achievement tests frequently may be the measurement desire since experimental studies mostly require monitoring participants' progress or comparing groups in terms of learning and understanding. Moreover, in this present study, the reason why documents were found to be one of the common instruments may be the fact that textbooks used as concepts analysis, students' writings, their reflection papers, their responses on tasks and their videos were considered as documents in qualitative studies, which forms approximately two-thirds of the all studies.

As the last question investigates the trends of the data analysing methods used in examined studies, the findings indicate that for quantitative studies, the descriptive analysis and *t*-test are used; for qualitative studies, document, descriptive and content analysis are the most frequently used analyses. These results support the findings of other studies claiming that the frequency (Ciltas et al., 2010) and mean/standard deviation are the most frequently used analyses for quantitative data and descriptive analysis for qualitative data (Tatar et al., 2014). Furthermore, it can be said that concept analysis and case study designs in qualitative studies may cause an increase in the number of documents, descriptive and content analyses used. Also, it can be concluded that experimental studies may result in the increase in number of descriptive analyses and *t*-tests used.

To sum up, it can be concluded that since DGS have been introduced in mathematics education, the researches mostly have started to show how to construct mathematical concepts/models in a DGS environment and how to integrate them in mathematics courses pedagogically. Also, researches have been conducted to test the effects of DGS on participants in terms of achievement, skills, competence, attitudes and cognitive processes, and also these researches were mostly carried out using qualitative designs with high school students and pre-service mathematics teachers.

5. Suggestions

- The mixed methods can be preferred more for DGS researches in the future.
- Elementary students and master/PhD students can be preferred as much as others.
- The investigation of DGS effect on something like achievement and skills separately should consider using the whole effect of DGS by using multiple data collection instruments.
- Additionally, the comparison of the experiment and control groups with/without DGS and the researches about the different teaching methods with DGS can be considered.
- Technological and pedagogical content knowledge level and integration of DGS to lesson can be studied more in the mathematics education field.

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Appendix-1

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