Impact of Interactive Engagement Methods on Students' Understanding and Application of Concepts of Electricity and Magnetism

Yamikani Kalolo[1], & Lakhan Lal Yadav[2]

Abstract

The study aimed at investigating the impact of the interactive engagement method on the students' conceptual understanding and application of the concepts of electricity and magnetism (E&M). The study involved 175 pre-service teachers, second-year physics students taking physics modules for E&M at the University of Malawi. We employed a quasi-experimental research design. Two groups (experimental and control) were formulated randomly. Experimental group learnt using interactive engagement techniques that included hands-on activities, pair problem-solving discussions, presentations to the entire class, computer interactive simulations like Physics Education Technology and Real-time Physics, and demonstrations. Traditional lecture method was used to teach students in the control group. Pretest and post-test were designed on electricity and magnetism (E&M) and administered to the groups. The data were analyzed to determine the influence of the treatment on the groups' understanding and application of E&M concepts. The major finding was that students taught using the interactive engagement method had a higher mean score on understanding and application of E&M concepts than students taught using traditional lecture method. The effect size and Hake's factor also show that students in the interactive approach group did better than those taught using traditional method. We propose some recommendations to science educators and stakeholders in education for improvement of teaching and learning of electricity and magnetism.

Keywords conceptual understanding; application of concepts; teaching electricity and magnetism; interactive engagement methods

Introduction

At the secondary school and college levels of education, electricity and magnetism (E&M) are considered central areas of physics curricula (Gunstone, Muhall & McKittrick, 2009; Ateş & Eryilmaz, 2011). E&M are among the most important sections of physics due to their many applications in everyday life; however, they are considered difficult topics in physics due to their abstract nature (Buck et al., 2007; Kola, 2017; Bayuni et al., 2018). Various efforts have been made for improvement of students' conceptual understanding of E&M, but still, the student achievements in physics especially in electricity and magnetism remain low (Aguilar et al., 2018; Mbonyiryivuze et al., 2019; Mbonyiryivuze et al., 2022).

E&M has been reported by different researchers to be abstract and difficult for both students and teachers (Aguilar et al., 2018; Mbonyiryivuze et al., 2019; Mbonyiryivuze et al., 2022), but yet this topic has wide applications to real-world experiences and acts as a hub for technological inventions (Hur et al., 2004; Chasteen & Pollock, 2008). Learners need to actively participate in organizing their information into a cohesive and global framework (Elby, 1999; Sabella & Redish, 2007). Therefore, teaching strategies that

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foster students' understanding and connectivity of science concepts taught in class to their real-world experience (Chasteen & Pollock, 2008; Aguilar et al., 2018) should be a desired aim for the science educators.

It is important that when teaching scientific ideas that appear abstract, like in E&M, science educators should possess a solid comprehension of those principles as well as creativity in methods of delivering of such concepts (Ateş & Eryilmaz, 2011; Bayuni et al., 2018). Such knowledge enables science educators to manipulate materials familiar to them and which are readily available so that through it, students can actively interact with content both minds-on and hands-on during the lesson. If this is done, the young upcoming scientists, engineers, and science educators in making will develop a better understanding of the scientific concepts that will be turned to life with applications, innovations, and improvements in performance.

Students are actively engaged when they are wholly participating and using their hands in the learning process. Unlike laboratory work, hands-on tasks do not always necessitate the use of specialized equipment and medium. Hands-on practices, according to Jodl and Eckert (1998), are focused on the use of common-place devices, simple set-ups, or inexpensive objects that are simple to locate and put together. Aguilar et al., (2018) suggested that rather than failing to conduct experiment due to high cost of purchasing apparatus, the experiments can be done by using inexpensive materials. Hence, in trying to understand the phenomenon in electricity and magnetism they used a video tracker to study RC-circuit experiment, visualizing physical phenomenon in charging and discharging capacitors and electromagnetic induction. Simulations such Physics Education Technology (PhET) have also been recommended in fostering the students' interaction (Banda & Nzabahimana, 2021; Bozkurt & Ilik, 2010). Other studies have also agreed with Anguilar et al., (2018) that simulations, demonstrations, interactive peer discussion sessions, etc, (Buck, et al, 2007; Chasteen & Pollock, 2008; Ateş & Eryilmaz, 2011) foster active engagement in learning and teaching and increase learners' conceptual comprehension and accomplishment in E&M.

In order to foster students' interaction with the scientific concepts and impact their understanding, hands-on activities can be performed with materials that cost less than a dollar per hand, and a few with no cost (Ateş & Eryilmaz, 2011; Aravind, 2015; Gupta, 2009; McGervey, 1995). These low-cost materials are easily available in homes, schools, and markets, often any fragment due to a split is not a catastrophic one. Hence, a student's safety is assured when he or she is manipulating the materials alone. These materials also enable student's continuous learning outside the school timetable, as the student can manage to get the materials sometime for free or with minimal cost and perform a demonstration or experiment while at home (Gupta, 2009). Furthermore, the use of inexpensive and common place materials also enables the student not to develop a mindset that the scientific concepts such as in physics, like E&M, require sophisticated equipment and tools which are expensive and often unavailable in most learning institutions in Sub Saharan Africa for demonstration to understand concepts and to see their application in real life.

When students are wholly involved in minds-on and hands-on activities, they get experiences in which multiple senses and mind work in synergetic way, which can address their various learning needs (Buck, Macintyre & Leslie 2007; Chasteen & Pollock, 2008; Ateş & Eryilmaz, 2011; Stickel, 2014; Kola, 2017; Ukoh, 2020). Students who are involved in active learning, their conceptual and analytical understanding, and critical thinking improve, which can reduce their failure rates and increase the retention rates. Also, when the students immediately apply their learned knowledge, the physics concepts become clearer, which increases meaningful learning and its retention.

Over the past years, several research studies have been conducted to investigate teaching approaches (Jimoyiannis & Komis, 2001; Hestenes, 1992; Mulhall et al., 2001; Smetana & Bell, 2012). However, research findings revealed that students continue to have many misconceptions and a lack of understanding of scientific concepts, which breeds bad academic performance (Yuliati et al., 2018; Ramnarain & Moosa, 2017). This might be a case due to timing for theory and practical, as traditionally the concepts are taught using conventional lecture methods and at specific times, laboratory experiments are arranged occasionally after the students have forgotten the concepts and arrangement of such experiments depends on the availability of equipment. Hence, rarely do the students interact and experience the taught scientific concepts (Chasteen, & Pollock, 2008; Ateş, & Eryilmaz, 2011). This is not a different case across Africa and specifically in Malawi, the academic achievements for students in physics have been discouraging (Dzama, 2006; Mlangeni, 2015; Cahya, 2016; Mutanu & Machoka, 2019; Kalambo, 2020; Lionetto et al., 2020).

Students' low achievements in Sub-Saharan Africa are usually attributed to poor instructional strategies which are teacher-centered rather than learner-centered (Uwizeyimana et al., 2018). Several studies elsewhere, for example, a study by Ateş and Eryilmaz (2011), have shown that interactive engagement enriched instruction improves students' achievement in terms of understanding and applications of science concepts in tests and examinations and even outside the school more than conventional instruction. Furthermore, studies elsewhere have shown that students who are actively engaged and interact with materials every day or once a week score substantially higher and are more motivated (Chasteen, & Pollock, 2008; Stohr-Hunt, 1996; Mulhal et al., 2001; Aguilar et al., 2018) than students who participate in hands-on activities once a month, less than once a month, or never.

An engaging and active learning situation has been reported that improves students' achievement in the subject matter (Buck, Macintyre & Leslie 2007; Chasteen & Pollock, 2008; Ateş & Eryilmaz, 2011; Ogunbowale, 2014; Kola, 2017; Ukoh, & Onifade, 2020). However, this has not been the practice by science educators as in most cases the issue of lack of materials is reported (Dzana, 2012), and less time is allocated for practical work. In traditional instruction setting, lecture and hands-on activity (laboratory session) are allocated different times on the teaching and learning timetable, hence students do not interact with the theoretical content and materials at the same time. However, several studies have recommended the need to integrate the hands-on activities and theory at the same time (Kola, 2017; Ukoh, & Onifade, 2020).

Literature for how pre-service teachers in Malawi interact with the content and materials at the same time when concepts of E&M are taught is unavailable, contrary to the case elsewhere. What is known is that traditional lecture method is followed by special time for laboratory session, often these activities are done on different times and dates. The practical sessions use complex laboratory equipment, which are expensive, and unfamiliar to student-teachers and their future learners which they are supposed to teach at secondary school level. This has left many African students with weak knowledge of physics. As a result, studies by different researchers still show that there is poor performance in physics, and particularly in E&M (Aguilar et al., 2018; Mbonyiryivuze et al., 2019; Mbonyiryivuze et al., 2022).

Researchers opine that students' poor performance in electricity and magnetism is as a result to instructional strategy that is employed in teaching and learning of the concepts of E&M. Therefore, this study was done to ascertain the impact of interactive engagement methods on the students' conceptual understanding and application of concepts of E&M at the University of Malawi.

Research Design

The study used a quasi-experimental design. Quasi-experimental designs provide a researcher control over when and what is measured (Best & Kahn, 1989; Maciejewski, 2020). Many limitations render conducting an actual experiment unfeasible for social science researchers; nevertheless, quasi-experimental designs remain the most often utilized approach (Dinardo, 2013). The pretest-posttest experimental design is a popular choice due to its ability to effectively manage threats to internal validity.

Sample

The study sample comprised of 175 second-year pre-service teachers in two physics classes, 104 students at the University of Malawi were in experimental group while 71 students at Domasi College of Education in control group.

The Experiment Procedure

The experimental group were involved in learning M&E using interactive engagement techniques that included hands-on activities, pair problem-solving discussions, presentations to the entire class, computer interactive simulations like Physics Education Technology (PhET) and Real-time Physics (RTP), and demonstrations. Theory and practice were merged throughout the course, and concepts were thoroughly taught, discussed, and practiced all in one session. The instructor was a trained teacher and was given a thorough orientation on the interactive engagement method including how to source teaching resources before the start of the treatment. The materials used throughout the treatment were locally available materials that are low cost and were familiar to both the instructor and the students. At the end of six weeks, the experimental group had nine sessions of hand-on activities, ten sessions of problem-solving, eight sessions of computer simulations and nine sessions of demonstrations.

Data Collection Instrument

Table 1 **Results of reliability test of the physics assessment test**

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	Number of Items
.736	.740	20

Physics Assessment Test (PAT) was designed by the researchers from recent course assessment tasks, past E&M course examination papers and the literature with respect to the learning outcomes as set in the curriculum for physics in the University of Malawi. The test covered all sections of electricity and magnetism I, meant for second year physics module which covers topics such as electrostatics, electric circuits, magnetism, electromagnetic induction, AC circuits and electromagnetic waves. Hence, the researchers made sure that the PAT items spread around all these topics.

The PAT was given to three lecturers at the University of Malawi's Physics and Electronics Department to thoroughly scrutinize it before administering it to students. Lawshe (1975) postulated that, if more than half of the panelists indicate that an item is important, then that item has some content validity. Content validity was utilized to determine the study's validity. Content validity refers to a technique for determining how important a topic is among experts or qualified judges (Lawshe, 1975).

Reliability was determined by making use of results from the pilot study. According to Fraenkel, Wallen, and Hyun (2012), reliability refers to the consistency of the scores acquired from measuring equipment when the same group of entities is handled under the same conditions across time. In this study, the reliability of instruments was determined using test scores for pretest and posttest from pilot study. Students from another university who did not take part in the research were used for the pilot study. The pilot study consisted of 90 students from a public university who were in second year of their study and had already learned the module in their first semester, this was done to establish the validity and reliability of the research instrument and Cronbach's alpha was calculated from their scores.

The reliability test was calculated using Cronbach's alpha. The most accepted value of Cronbach's alpha is 0.7. Table 1 shows the results of reliability test for findings of the pilot study.

Data Collection and Analysis Procedures

All groups were subjected to a pre-test, before the treatment was given, to determine if the groups were at the same degree of knowledge. In the six weeks that followed, the experimental group was taught M&E using interactive engagement method and the control group was taught M&E using the traditional lecture approach. During this period, observations were made on how the students were manipulating the simple local materials and how they handled the complex materials in the laboratory during lab activities. This formed part of hands-on skills activities. After the six weeks of learning, the students in both groups wrote a post-test to examine the influence of the treatment.

Collected data was analyzed using SPSS version 23.0. Descriptive statistics and two inferential statistical tools - independent t-test and paired t-test - were used in analyzing the data to answer the research questions.

Results and Discussion

The purpose of this research study was to investigate the impact of interactive engagement methods on the students' conceptual understanding and application of the concepts of electricity and magnetism among second-year students at the University of Malawi. This section presents the results and discussion of the research outcomes for pre-test and post-test for the two groups involved in this research study.

Table 2 show the results for pretest and posttest for the control and experimental groups respectively.

Table 2. Results of performance for pretest and posttest for both groups

Group	Test	Score Range	Number of Students	Mean	Min.	Max.	Std. Dev.
Control	Pretest	0 - 100	70	22.67	15	27	1.63
	Posttest	0-24	23	28.07	18	39	5.35
		25-30	24				
		31- 35	16				
		36-40	7				
Experimental	Pretest	0 - 100	105	20.75	11	45	3.74
	Posttest	0 -55	0	67.52	43	78	5.91
		56-60	13				
		61-65	27				
		66-70	29				
		71-75	26				
		76-80	10				

From Table 2, students' performance in pre-test in both groups was low, as shown by group's mean score, which was 22.67 and 20.73, for control and experimental groups respectively. The independent t-test of the average scores in pre-test for the two groups were found not statistically significant different (see Table 3) as it was greater than p-value (0.05) of which the null hypothesis was set, and it was accepted. This means that the students in all the groups were at the same level at the time module was introduced, similar to the studies elsewhere (Ogunbowale, 2014; Kola, 2017; Ukoh, & Onifade, 2020) which used similar approach, as such it enabled the researchers to administer intervention for a period of six weeks.

Table 3 Results of the pre-test independent samples t-test

	T	Df	Sig. (2-tailed)	Mean Dif.	Std. Error Dif.	95% Confidence Interval of the Difference	
						Lower	Upper
Equal variances assumed	44.625	173	.105	39.424	0.883	37.68	41.168
Equal variances not assumed	45.612	158.548	.145	39.424	0.864	37.717	41.131

Mean scores for post-test for the two groups are given in Table 2. The analysis of means using independent t-test, gave a 2- tailed significant difference of (0.105). This difference is statistically not significant as it is greater than alpha level (p-value) (Buck, Macintyre & Leslie 2007; Chasteen & Pollock, 2008). Hence, we accept the alternate hypothesis; this means that there is no statistically considerable difference in students' understanding and application of concepts of electricity and magnetism before the experiment.

To show the score-gain in the performance of both groups, a paired t-test was used. The results are given in Table 4.

Comparing the means of the post-test results for experimental and control groups, which are 67.52 and 28.07 respectively (see Table 4), we found that the mean for control group was much lower than that for experimental group, which was found to be statistically significant as shown in Table 4. The findings show that the interactive engagement method is powerful in refining students' conceptual understanding and applications of the concepts of electricity and magnetism, this is consistent with findings of other researchers (Buck et al., 2007; Chasteen & Pollock, 2008; Ateş & Eryilmaz, 2011; Ogunbowale, 2014; Kola, 2017; Ukoh & Onifade, 2020; Zajda & Zajda,2021).

The comparison was also made by considering the sections of second year module for electricity and magnetism which

Table 4 Results of the post-test independent samples t-test

Group	N	pre-test Mean	pre-test Std. Dev.	post-test Mean	post-test Std. Dev.	Mean Gain	df	t	Sig.
Control	70	22.67	5.35	28.07	5.347	5.36	173	45.841	.000
Experimental	105	20.75	3.74	67.52	5.906	46.17			

the students from two groups performed in the pre-test results, see Table 5.

From Table 5 it was found that the results by section was random with no pattern, this again agrees with the significant difference which was found to have greater than the p-value. Meaning that the students were at the same level of knowledge even within the sections of the module at the beginning of the study. Similar analysis was made for results for post-test results (see Table 6), it was found that there was a gain in scores of both groups, but much greater difference was seen in experimental group. This implies that there was a greater improvement in students' performance in terms of conceptual understanding and applications of the concepts of electricity and magnetism when the students are actively engaged. This agrees with findings of other studies that interactive engagement method that involves students wholly mind-on and hands-on has significant impact in improvement of students' performance (Buck et al., 2007; Chasteen & Pollock, 2008; Ateş, & Eryilmaz, 2011; Boateng, & Mushayikwa, 2022).

Table 5 **Descriptive statistics of pre-test scores on conceptual understanding for the concepts of electricity and magnetism**

Group / Content	Topics	Experimental			Control		
		Min.	Max.	Mean	Min.	Max.	Mean
Electricity	Electric charge and Electric field	0	4	1.50	1	2	2.00
	Gaus's Law	1	5.5	3.00	1	4.5	3.00
	Electric potential	0	4	2.50	0	5	2..50
	Capacitance and Dielectrics	0	4	1.50	0	4	2.00
	Current, Resistance and electromotive force	2	7	4.00	3	6	3.50
	Direct current circuits and alternating currents	0	5	3.00	0	7	3.00
Magnetism	Magnetism & magnets	1	4	2.00	1	5	2.00
	Source of magnetic field	1	6	3.00	1	6	3.00
	Magnetic field due to current carrying wire	0	5	2.50	0	4.5	2.35
	Introduction to Faraday's law	0	4	2.00	0	3	2.00
	Generators and transformers and motors	0	5	2.00	0	5	2.00
	Indicators in AC circuits	0	1.5	1.00	0	2	1.00
	Electromagnetic waves	0	3	1.50	0	3	1.50

To examine the magnitude of the effect of the interactive engagement method compared to traditional method, we computed Cohen's d and normalized gain. Cohen's d or the effect size was computed using following relation.

$$\text{Effect size} = \frac{\mathrm{M2-M1}}{\mathrm{SD_{pooled}}},$$

where

$\mathrm{M2} = \text{Mean score of the experimental group in post} - \text{test}$

Table 6 **Descriptive Statistics of Students' Performance in Post-test on Conceptual Understanding for the Concepts of Electricity and Magnetism**

Group / Content	Topics	Experimental			Control		
		Min.	Max.	Mean	Min.	Max.	Mean
Electricity	Electric charge and Electric field	5	11	8.50	2	7	3.00
	Gaus's Law	4	9	6.50	1	6	3.00
	Electric potential	3	10	5.50	0	5	2..50
	Capacitance and Dielectrics	4	8	4.50	0	6	3.00
	Current, Resistance and electromotive force	6	16	9.00	4	8	3.50
	Direct current circuits and alternating currents	7	18	9.25	0	9	4.10
Magnetism	Magnetism & magnets	5	12	5.50	1	8	3.00
	Source of magnetic field	6	13	6.50	2	8	3.23
	Magnetic field due to current carrying wire	5	9	5.50	0	5	2.37
	Introduction to Faraday's law	3	9	5.00	0	6	2.16
	Generators and transformers and motors	8	14	10.61	3	8	3.52
	Indicators in AC circuits	8	19	9.53	1	4	2.15
	Electromagnetic waves	5	11	8.50	1	4	2.50

$M1 = \text{Mean score of the control group in post} - \text{test}$

$SD_{pooled} = \text{Pooled standard deviation for both groups}$

$$= \sqrt{\frac{(SD1)^2+(SD2)^2}{2}}$$

SD_1 and SD_2 are the standard deviations for the control and experimental groups, respectively.

Effect size of the treatment calculated from the formula was 7.27, which is a very large effect size of the treatment. An effect size of 7.27 indicates that the variance between the average of the experimental group and the control group is above the standard deviation of either of the group (Cohen, 1988; Sawilowsky, 2009). The result shows the huge significance of the treatment. Hake factor $< g >$ also known as the normalized class gain (Hake, 1998), was also calculated to establish how much normalized learning gain was achieved in the two groups.

$$\text{Hake factor} < g > = \frac{\text{class average \% of posttest} - \text{class average \% of pretest}}{100\% - \text{Class average \% of pretest}}$$

For the experimental group, which was taught using interactive engagement activities, $< g >$ is 0.59, which is close to the high learning gain, while for the control group, which was taught using conventional traditional lecture method, $< g >$ is 0.069, which is very low learning gain. The comparison of $< g >$ for the two groups shows that interactive engagement methods contributed to good understanding and application of the concepts of electricity and magnetism unlike the conventional traditional lecture methods.

The power of interactive engagement methods as suggested by other researchers is that it gives students' opportunity to discuss, visualize and experience physics phenomena which enable them to have differing points of view in physics which are then consolidated to clear scientific understanding of the concept matter (Buck et al., 2007; Chasteen & Pollock, 2008; Ateş, & Eryilmaz, 2011; Boateng, & Mushayikwa, 2022). This has been proven by the students' performance in the experimental group which has been found to be statistically significant as compared to the results in the control group which was low.

The study's findings are in line with the learning principle which says that "I hear, I forget. I see, I remember. I do, I understand" (Bansal & Ramnarain, 2023). Hence it is vital that teaching and learning in a regular class should always employ interactive engagement method. This inspires higher level understanding which in turn leads into a higher level of academic achievement and more meaningful learning in response to the observed changes in the students' academic performance. The students' performance in experimental group after intervention underscored significance of interactive learning activities that it engages learners both hands-on and minds-on and efficiently stimulate more receptive to new knowledge (Buck et al., 2007; Chasteen & Pollock, 2008; Ateş, & Eryilmaz ,2011; Boateng, & Mushayikwa, 2022).

When concepts of the day's lesson are explained while involving the students with hands-on and cognitive activities, they improve their understanding of electricity and magnetism and their ability to apply it. The results of the study are also consistent with other studies (Buck et al., 2007; Chasteen & Pollock, 2008; Ateş & Eryilmaz, 2011; Ogunbowale, 2014; Kola, 2017; Aguilar et al., 2018; McMillan et al., 2018; Ukoh, & Onifade, 2020), which noted that hands-on and minds-on activities are effective instructional methods that help students' understanding and improves performance in science subjects.

Conclusion

In conclusion, students taught using the interactive engagement method (experimental group) had a higher mean score in conceptual understanding and application in electricity and magnetism than students in the traditional lecture method (control group), showing that students in the interactive lecture approach did better.

The interactive engagement method has shown to be an effective way to increase conceptual knowledge and applications in physics classes this is in agreement with the findings of other researchers (Crouch et al., 2007; Ogunbowale, 2014; Kola, 2017; Ukoh, & Onifade, 2020). The students in the interactive class had time to discuss, visualize and experience physics phenomena which enable them to have differing points of view in physics with those taught using conventional methods, which could explain the disparity in their results.

Recommendations

The above findings prompt the researchers to make the following recommendations to science educators and stakeholders in education as far as the teaching of physics is concerned for abstract concepts such as related to electricity and magnetism.

(i) Science educators should use interactive engagement methods in teaching E&M, to enhance conceptual understanding and application.

(ii) Whether difficult or simple concepts in physics should be explained by engaging the students with an experience of such phenomena, either by use of computer simulations, demonstrations, and discussions which should also be connected to real-life applications so that the students should see the use of such concepts in day-to-day life.

(iii) No distinction should be made as to when to involve students with mind-on and hands-on when explaining the concepts in physics such as electricity and magnetism and the hands-on activities should be made from simple locally available resources so that the students continue learning and linking the concepts to real-world as this is the goal of science that students should understand the natural world.

(iv) When a demonstration has been chosen to aid in explanations of physics concepts such as electricity and magnetism, the demonstrations should be developed by the students with the guidance of the instructor, not the other way round.

(v) Materials used to teach concepts of physics (electricity and magnetism) should not be complex, should be simple, familiar to students and with low cost, as this can help to remove the abstract view of such concepts from the students, and enable students to be practicing the concepts at home and be able to make connections to daily life and solve problems.

(vi) The future science educational research in electricity and magnetism (physics and other sciences) should consider examining the impact of interactive engagement methods on students' ability to discover and innovate new knowledge that may best solve present and future challenges.

Limitations

The study did not face challenges, it went smoothly. This might be the case that study was being carried out in a higher learning institution in which the need of having research is understood. However, the study did not compare contributions of interactive engagement methods against students' self-motivation towards E &M, hence the future studies should consider researching on it.

Ethics Statements

Necessary procedures were followed to get approval from appropriate authorities, this include writing and presenting the research proposal to both University of Rwanda- College of Education (UR-CE) and University of Malawi and to get authorization for conducting research from the Research Unit of the UR-CE, this was successful, the permission was granted for the research.

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