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Using the learning curve theory in the investigation of on-site craft gangs' blockwork construction productivity

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Abstract
Purpose – The purpose of this paper is to investigate how on-site blockwork craft gangs' learning impacts productivity within the production environment on-site to optimise their productivity.
Design/methodology/approach – The research is adopting a quantitative method with the observation of seven craft gangs' blockwork with an average of five members in each gang, using the learning curve model application in a 17-storey tri-tower construction project in Nigeria. The linear regression method was employed in the analysis stage of this study using labour-recorded productivity time input as the dependent variables.
Findings – The paper provides empirical insights about the significance of on-site craft gangs' learning. The overall blockwork craft gangs learning observed at the site level shows an average learning rate of 94.21 per cent resulting in 5.79 per cent improvement gains.
Research limitations/implications – Due to the nature of the study and the research question, the observations in this research study were limited to FCDA construction project in Nigeria. The limitation of this scenario is that the research results may lack generalisability. Therefore, there is the need for further study on the learning rate.
Practical implications – This research study includes the implications for the development of on-site blockwork craft gangs learning; the significant impact of learning rate of 94.21 per cent resulting in 5.79 per cent improvement gain can be used in the planning and to fast track the productivity of craft gangs' construction.
Originality/value – This paper identified the need to improve construction productivity through craft gangs' on-site learning with the application of the learning curve theory.

Keywords Construction productivity, Blockwork, Craft gangs', Learning curve theory, On-site learning, Quantitative research method, Standard observation

Paper type Research paper

Introduction
Construction is a challenging industry that uses many capitals; it accounts for an important amount of gross domestic product (GDP) of some advanced and emerging countries (Tucker *et al.*, 2005). In advanced European countries, the building industry accounts for 10 per cent of the GDP and even more in emerging countries (Chen *et al.*, 2009; Hassan and Mccafferr, 2002). The provision of infrastructure is an important measure of growth and improving infrastructure to provide for the varying demands of a fast-evolving world is important for economic activity and growth (Attar *et al.*, 2012).

Labour costs contribute to a large portion of the total contract cost of a construction project compared to other cost elements such as equipment and material; the labour contract costs have the probability of being reduced by the appointment of a competent

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building team (Odesola and Idoro, 2014). An upturn inefficiency tends to reduce the overall workforce productivity of the construction project (Hanna *et al.*, 2008).

Craft gangs' learning systems perform a significant function in enhancing construction workforce productivity (Wong and Neck, 2010). The conventional learning platforms occur in the construction industry union sectors in the USA (Wong and Neck, 2010). However, these conventional programmes are unreliable and enjoy insignificant support from the government (Wong and Neck, 2010). The official traineeship platforms in Canada are regulated and maintained by the management in the relationship with the unions and private organisations and related formal preparation learning programmes exist in other developed countries of the world. This problem associated with the deficiency of building craftsmanship learning in the USA can be related to the likely cause for discouraging US production growth in the building engineering industry (Wong and Neck, 2010).

In Nigeria, construction projects' failure is a result of contractor's poor performance which is characterised by the poor skill of workers, rework, low output, late accomplishment, cost overruns, high accident rate, poor labour practice and conflict (Usman *et al.*, 2012). Qualitative and quantitative studies were carried out in Nigeria by Usman *et al.* (2012); the study identifies the inadequacy of knowledge in the skill of workers as a part of the factors affecting the success of productivity in the Nigerian building industry. Furthermore, the construction industry is concentrating on the company profit and undermining the workers who perform the work (Usman *et al.*, 2012). Construction labour productivity has become one of the major concerns of the building industry as it is generally labour-demanded and enhancing labour performance will be advantageous for the construction industry (Tran and Tookey, 2011).

The last decade in Nigeria has experienced a boom in construction output; there has been an expansion in public sector developments such as rehabilitation of infrastructures, highway and public housing schemes (Oluwakiyesi, 2011). However, despite these construction projects in the country, the construction sector is still struggling with many fundamental issues. The issues include the incompetent skill of workers, inadequate technology and poor supervision. Other issues include the adoption of basic hand tools and delay in supply of materials during construction process (Oluwakiyesi, 2011; Usman *et al.*, 2012; Isa *et al.*, 2013; Odusami and Unoma, 2011; Odesola, 2012).

Previous studies on construction labour productivity have been limited to identifying the factors affecting labour productivity and determining their impact on performance (Oluwakiyesi, 2011; Usman *et al.*, 2012; Isa *et al.*, 2013; Odusami and Unoma, 2011; Odesola, 2012). These studies have mainly utilised perception surveys and interviews, focusing on the key constraints and attempting to quantify the performance of the craftsmen. One would expect that craft gangs' learning impacts on the productivity subject to the inevitable problems that arise on site. However, no studies have been conducted on how blockwork craft gangs' learning impacts productivity within the production environment.

The question then becomes:

RQ1. How can the impact and relative influence of on-site learning be measured on blockwork craft gangs' productivity within the production environment?

To date, research studies with the objective of shedding light on this area are scarce. In view of the above, the study purpose is to investigate the impacts of on-site blockwork craft gangs' learning on productivity within the production environment in order to improve productivity in the construction industry.

In order to develop an understanding of previous research conducted on construction productivity improvement and the progress developed in this area, the paper starts with a literature review of factors affecting construction productivity. It also briefly introduces an overview of the learning curve theory (LCT), presents the research method and analysis and finally provides the result discussion including conclusion and recommendations geared towards further enhancing the investigation of on-site craft gangs' construction productivity using LCT.

Literature review

Factors affecting construction productivity

Inadequate knowledge in workmanship is one of the factors affecting the success of productivity in the Nigerian building industry (Usman *et al.*, 2012). A qualitative and quantitative study carried out shows that the construction industry is concentrating on the company profit and undermining the workers who actually perform the work (Usman *et al.*, 2012). Furthermore, Usman *et al.* (2012) classified the causes of construction projects failure in Nigeria as contractor's poor performance which is characterised by poor workmanship, rework, low output, late accomplishment, cost overruns, high accident rate, poor labour practice and conflict. Darnton (2006) stated that the construction industry is affected by the following problems: supply of improved manpower capable of greater productivity in carrying out simplified sequential operations, maintaining several craftsmen capable of experienced, skilled work and inadequate training of craftsmen.

A number of researchers have noted that there is a recent deficiency of experienced manpower and this is giving many building industry difficulties in dealing with the recent improvement in building work and the full amount of work they now have (Alinaitwe *et al.*, 2007; Ciob, 1987; Odusami and Unoma, 2011). Hanafi *et al.* (2010) stated that competency of site supervisors is an important contributing factor that influences on-site labour productivity. In a related study, Chigara and Mangore (2012) noted that inadequate skilled manpower and inexperience labour negatively influence construction labour productivity in Zimbabwe.

Alinaitwe *et al.* (2007) ranked deficiency in crafts worker's knowledge and incompetent supervision as top two significant factors causing differential productivity of craft workers in developed and developing countries. In the same way, Odusami and Unoma (2011) noted that the differential output in productivity could relate to inadequate and poor knowledge of workers in the construction industry. Moselhi (2010) identified the following constraints that can influence productivity daily: craft gangs training, crew composition, and weather, the height of work and construction method. Enhancing the skill of craftsmen will assist in addressing these problems in project delivery in Nigeria.

LCT

The LCT has its origin in the aircraft industry in 1936 when Wright conducted a research and published an article in Aeronautical in February 1936, according to Norfleet (2004). The presence of diverse terms for the theory of learning curve, at the elementary level, explains the same phenomenon: the unit's rises, the capitals necessary to complete the production unit per man-hour or cost decline (Norfleet, 2004). Couto and Teixeira (2002) noted that the period necessary to achieve same activities sequentially and in the same environments is anticipated to decline to a definite significance value. Therefore, it is feasible to introduce this learning effect in construction repetitive work planning processes, hence bringing about an expected productivity rise after the first repetitive work experience.

Granerud and Rocha (2011) stated that learning comprises of the enhancement of innovative experience, expertise and performance, the corrections of errors and enhancement of modern method, and also the improvement of recent standards. Arashpour *et al.* (2012) carried out research on organisational learning and noted that it is projected to lead to constant development. The study also suggested that opinion, methods and knowledge from inside or outside the industry are combined to enhance the company performance.

A research study conducted by Parker and Oglesby (1972) on building construction work shows that the projected percentage of learning in most construction work falls within the range of 90-30 per cent, it means that if a craft gang or worker follows the 70 per cent learning model and it is expected that the time to build the first unit is 1,000 man-hours, it implies that in order to build the next two unit, it will require 70 per cent of 1,000 man-hours or 700 working hours, then the time to erect the subsequent units will be 70 per cent of the previous units. However, the LCT states that as the units number rises the production rate of construction stabilises, since the workers or gangs are becoming more familiar with the procedure of work (Parker and Oglesby, 1972).

Couto and Teixeira (2005) stated that applying the learning curve model in the building engineering is complemented with some challenges because building activities generally take place in diverse and unique environmental condition. In addition, their study observed that the construction industry works are different and are not repetitive, unlike the manufacturing industry where the workers could perform their work repeatedly. However, their study argued that the main reason why building engineering shows a low level of productivity compared to other manufacturing industry is that the building tasks are characteristically different and not repetitive.

In a related study investigated by Thomas *et al.* (1986) on 65 different labour-intensive productivity data from construction activities shows great coefficients of determination in the relationship among the cycle numbers and the time. However, notwithstanding the low response rate of the building industry in the application of the LCT, prior research work has shown the significance of this model to construction productivity (Norfleet, 2004; Couto and Teixeira, 2005). Thomas *et al.* (1986) noted that to achieve the most profits from the development of the LCT, investigators should focus on evolving scientific models of learning curves; this model illustrates the time per cycle of repetitive activity. The purpose of the scientific technique is to forecast the increased output in the repetitive work. The development of straight line unit model has assumed that the rate of learning is constant (Jarkas, 2010). However, the theory considers the adjustment of previous experience.

An investigation was carried out into rebar fixing labour productivity using the application of the LCT to quantify the effect of learning on the rebar fixing productivity; the study found an important relationship between learning and productivity improvement due to the repetition in rebar construction (Jarkas, 2010). However, Jarkas (2010) noted that it is significant to distinguish between production increase arising from the effect of learning due to the repetition of material. The earlier may be referred to as the phenomenon of learning, while the latter can be described as material repetition effect.

Several studies have investigated the application of the LCT in the construction industry; these studies have revealed that the benefits of the LCT to construction labour productivity are very significant (Parker and Oglesby, 1972; Couto and Teixeira, 2005; Thomas *et al.*, 1986; Long *et al.*, 2013; Jarkas, 2010).

Research methodology

The researcher employed a quantitative research method using the application of the theory of learning curve. A standard observation form was used in the collection of data from the seven craft gangs observed on the 17-storey tri-tower construction site located in Abuja, Nigeria. The observation form in Figure 2 was used to record the observed productivity time inputs and the associated productivity output of the seven craft gangs' blockworks. The forms were designed to include general site information. The observation form or sheets were recorded for each working day of the craft gangs' blockwork observed in the on-going construction project. The observation of the craft gangs' repetitive blockwork activities took a period of 12 weeks for a total of 16-26 observations among the blockwork craft gangs. In addition, selected craft gangs' blockwork activities which are repetitive in nature within the observed projects sites were also monitored to complement the required productivity data.

Data analysis

The linear regression technique which is also known as the ordinary least square technique was used with the straight-line learning curve model in the analysis of this study. Craft gangs' productivity time recorded input was used as the dependent variable for predicting the regression model. PHStat Microsoft Excel software add-in was also used to aid the regression analysis. The following steps were adopted in the analysis phase: first, the basic assumptions of the regression model were verified in order not to violate the assumptions by quantifying the regression model coefficients. Second, the overall usefulness of the predictive regression model was statistically determined to assess the importance of the result. In addition, the standardised regression model was quantified to determine the impact of learning on the craft gangs and finally, the learning rate of each craft gang and the overall average learning rate were determined.

Table I represents a sample detail of the correlation coefficient which was used to generate the regression model in Table II. The correlation coefficient is the relationship between the average difference in craft gang blockwork productivity between first and repeated cycle numbers of blockwork. Table II represents a sample regression model for craft gang productivity. The relationship between the cycle numbers and the craft gangs' productive time input was determined at a level of 5 per cent significance by substituting the observed, recorded productive time input into the linear regression equation, as presented in the following equation:

$$Y = \alpha + \beta X \tag{1}$$

From the regression equation, α and β indicate the intercept and the slope of the linear regression model. The slope and the intercept are thus estimated:

$$\beta = \left(n\sum xy - \sum x \sum y\right) / \left(n\sum x^2 - \left(\sum x\right)^2\right) \tag{2}$$

$$\alpha = \bar{Y} - \beta\dot{X} \tag{3}$$

From Equations (2) and (3) and Table II, we get a sample regression model with $\alpha = 6.27$, $\beta = -0.14$, $\Upsilon = -0.77$. Where α is the intercept, β is the slope of the linear curve, and Υ is the correlation coefficient of the observed gangs. Hence, the general regression model for the observed sample blockwork craft gangs is as given below:

$$Y = 6.27 - 0.14\times$$

where Y is man-hours = 6.27–0.14 cycle numbers.

Table III represents the overall regression model for blockwork craft gangs. In the regression equation, α and β indicate the intercept and the slope of the linear regression model. The slope and the intercept are estimated with the regression model:

$$\beta = \left(n\sum xy - \sum x \sum y\right) / \left(n\sum x2 - \left(\sum x\right) 2\right), \quad \text{and} \quad \alpha = \dot{Y} - \beta\dot{X} \tag{4}$$

where Y is Man-hours and X is the cycle numbers.

Table I.
Sample craft gangs' correlation coefficient

GANG 1605 correlation coefficient

	LN Man-hours	LN Cycle No.	C	D	E	F	G	H	I	J	K	L	M	N	O	P
S/N	Y	X	XY	X^2	Y^2	$n\sum XY$	$\sum X\sum Y$	$n\sum X^2$	$(\sum x)^2$	$n\sum Y^2$	$(\sum Y)^2$	H-I	J-K	(L×M) ^½	F-G	$r =$ O/N
1	6.26	–	0	–	39.2252	3,394.727773	3,418.25	1,295.19	1,123.29	10,407.43	10,401.98	171.90	5.45	30.61	−23.52	−0.77
2	6.21	0.6931	4.30692	0.4804	38.6138											
3	6.05	1.1098	6.71651	1.2317	36.6267											
4	6.05	1.3862	8.38651	1.9216	36.6025											
5	6.03	1.6094	9.70468	2.5902	36.3609											
6	6.03	1.7917	10.804	3.2102	36.3609											
7	6.01	1.9459	11.6949	3.7865	36.1201											
8	6.00	2.0794	12.4847	4.3239	36.0480											
9	5.99	2.1972	13.1612	4.8277	35.8801											
10	5.99	2.3025	13.792	5.3015	35.8801											
11	6.02	2.3978	14.4348	5.7494	36.2404											
12	5.95	2.4849	14.7852	6.1747	35.4025											
13	5.96	2.5649	15.2868	6.5787	35.5216											
14	5.99	2.6390	15.7984	6.9643	35.8382											
15	5.92	2.7080	16.0314	7.3333	35.0464											
16	5.57	2.7725	15.4428	7.6868	31.0249											
17	5.95	2.8332	16.8592	8.0270	35.4096											
$\sum$	102	33.5155	199.69	76.1878	612.2019											

	GANG 1605 regression model for blockwork													
	LN Man-hours	LN Cycle No.	C	D	E	F	G	H	I	L	O			
S/N	Y	X	XY	X^2	Y^2	nΣXY	ΣXΣY	$n\Sigma X^2$	$(\Sigma x)^2$	H-I	F-G	$\beta = O/L$	$B\dot{x}$	$\alpha = \bar{Y} - \beta\dot{x}$
1	6.26	–	0	–	39.2252	3,394.727773	3,418.25	1,295.19	1,123.29	171.90	−23.52	−0.13683	−0.269757593	6.269175
2	6.21	0.6931	4.306923	0.4804	38.6138									
3	6.05	1.1098	6.71651	1.2317	36.6267									
4	6.05	1.3862	8.38651	1.9216	36.6025									
5	6.03	1.6094	9.704682	2.5902	36.3609									
6	6.03	1.7917	10.80395	3.2102	36.3609									
7	6.01	1.9459	11.69486	3.7865	36.1201									
8	6.00	2.0794	12.48472	4.3239	36.0480									
9	5.99	2.1972	13.16123	4.8277	35.8801									
10	5.99	2.3025	13.79198	5.3015	35.8801									
11	6.02	2.3978	14.43476	5.7494	36.2404									
12	5.95	2.4849	14.78516	6.1747	35.4025									
13	5.96	2.5649	15.2868	6.5787	35.5216									
14	5.99	2.6390	15.79837	6.9643	35.8382									
15	5.92	2.7080	16.03136	7.3333	35.0464									
16	5.57	2.7725	15.44283	7.6868	31.0249									
17	5.95	2.8332	16.85924	8.0270	35.4096									
Σ	101.9901	33.5155	199.6899	76.1878	612.2019									

Table II.
Sample regression model for blockwork craft gang

From the overall regression model in Tables III, $\alpha = 6.17$, $\beta = -0.09$, and $\Upsilon = -0.82$. Where α is the intercept, β is the slope of the linear curve, and Υ is the correlation coefficient of the observed gangs, as presented in Tables I and II sample craft gangs' correlation coefficient and regression model. Hence, the general regression model for the observed blockwork craft gangs is given as follows:

$$Y = 6.17 - 0.09x \tag{5}$$

That is, man hours = 6.17−0.09 cycle numbers.

The LCT states that whenever the production quantity/number or unit doubles, the cumulative productive hour or cost required for the production declines with a percentage of the previous quantity. These declines in percentage are known as the learning rate. It determines the rate of learning achieved in the production process (Thomas *et al.*, 1986; Long *et al.*, 2013; Jarkas, 2010). In the learning curve, the rate of learning is established by the slope. The lesser the percentage of learning, the more is the learning achieved, i.e. 100 per cent rate of learning means that learning has not taken place but a learning less than 100 per cent indicates that learning has taken place (Jarkas, 2010; Long *et al.*, 2013).

From the overall craft gangs' blockwork regression model in Table III, the craft gangs' regression model shows a negative relationship between the blockwork gangs' inputs and the cycle numbers. These indicate that there is a relationship with the learning curve model. It also means that as the cycle numbers increases, man hour inputs decrease.

The research question is as follows:

RQ1. How can the impact and relative influence of on-site learning be measured on blockwork craft gangs' productivity within the production environment?

As a result of answering the question on the observed blockwork craft gangs, the productivity learning impact was analysed using the "straight-line unit learning model, and it is expressed as a power function" (Jarkas, 2010; Couto and Teixeira, 2005; Thomas *et al.*, 1986). The logarithmic mathematical model underlying the straight-line learning curve expressions is:

$$Y = T_I \times (x)^b \tag{6}$$

where Y is the cost, man-hours, or time required to perform the repeating unit; T_I the cost, man-hours, or time necessary to perform the first unit; x the cycle number of the unit; and b represents the slope of the logarithmic curve (Couto and Teixeira, 2005). This can be explained as:

$$b = \frac{\text{In}S}{\text{In}2} \tag{7}$$

Table III. Overall regression model for blockwork craft gangs

	GANG 1601	GANG 1602	GANG 1603	GANG 1604	GANG 1605	GANG 1606	GANG 1607	AVERAGE
α	6.08	6.11	6.15	6.17	6.27	6.20	6.21	6.17
β	−0.03	−0.06	−0.08	−0.09	−0.14	−0.11	−0.10	−0.09
Υ	−0.64	−0.84	−0.86	−0.87	−0.77	−0.97	−0.83	−0.82

Notes: The overall regression in Equation (2) and (3): $\alpha = 6.17$, $\beta = -0.09$, $\Upsilon = -0.82$. Where α is the intercept given by the standard linear equation, β is the slope of the linear curve, and Υ is the correlation coefficient of the observed gangs, as illustrated in Tables I and II sample craft gangs' correlation coefficient and regression model

In Equation (7), $S=$ learning rate and it is described as the percentage reduction in the cost of man hours. Equation (7) can be re-expressed as:

$$S = \left(2^{b}\right) \times 100 \qquad (8)$$

Discussion of results

Blockwork craft gangs on-site learning impact on productivity

Table IV and Figure 1 summarise the observed results obtained from the seven craft gangs' blockwork learning rate productivity. The rate of learning (S) is determined by substituting the slope (b) into Equation (8) as presented in Table IV that is –0.09, into the learning rate Equation (8) as follows: $S=(2^{-0.09}) \times 100 = 94.21$ per cent. The influence of learning rate from the summary in Table IV shows average learning of 94, 21 per cent resulting in 5.79 per cent productivity improvement. However, craft gangs' number G1601 and number G1602 show insignificant learning ranging from 98.14 to 96.08 per cent.

Project ID	Total cycle number	Average man-hours	Coefficient of correlation $\mathscr{R}$	Learning rate (S)	% gain	Influence of learning on blockwork productivity
G1601	26.00	6.02	–64.04	98.14	1.86	Insignificant
G1602	24.00	5.98	–83.62	96.09	3.91	Insignificant
G1603	16.00	5.99	–86.26	94.65	5.35	Significant
G1604	17.00	5.99	–87.32	93.76	6.24	Significant
G1605	17.00	6.00	–76.83	90.95	9.05	Significant
G1606	17.00	5.97	–96.75	92.36	7.64	Significant
G1607	18.00	6.02	–82.61	93.54	6.46	Significant
AVERAGE			–82.49	94.21	5.79	Significant

Notes: The learning rate (S), expressed as a percentage, is quantified by substituting the slope (b) shown in Equation (6), that is –0.09, into the learning rate equation as follows: $S = (2^{-0.09}) \times 100 = 94.24$ per cent, this is approximately 94 per cent as illustrated in Table IV. A learning rate value of 100 per cent indicates that no learning has taken place. A value lower than 100 per cent indicates the justification of the learning curve theory, a negative relationship between man-hours and cycle numbers is determined, that is, man-hours decreases as the cycle numbers increases. In both cases, the learning theory is applicable to the blockwork craft gang observed

Table IV. Summary of the blockwork crafts gangs' learning rate

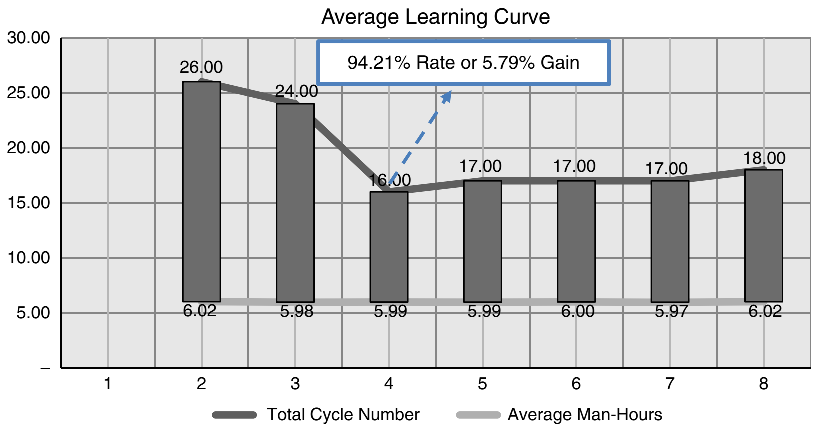

Figure 1. Summary of craft gangs' average learning rate

Long *et al.* (2013) carried out an observational study on the relationship between building floor and productivity using LCT and found an increase in the first five floors construction. These findings are related to the finding of Long *et al.* (2013). Like the building floor and labour productivity of the structural work together with formwork installation and rebar fabrication activity, the decrease in productivity of craft gangs' number G1601 and G1602 blockwork activity from the observed factors might be due to the craft gangs' crew composition and deficiency in crafts gangs' knowledge of construction method. These factors relate the study conducted by Usman *et al.* (2012), stating that inadequate knowledge in workmanship is one of the factors affecting the success of productivity in the building construction industry. These factors are also in association with previous studies that acknowledge a deficiency in craft gangs' knowledge as one of the key factors affecting construction labour productivity (Chigara and Mangore, 2012; Oluwakiyesi, 2011; Alinaitwe *et al.*, 2007). This factor on construction method is related to the study conducted by Moselhi (2010) and found that construction method is one of the key factors that can influence labour productivity daily.

The learning rate found in craft gangs' G1601 and G1602 is in relation to the findings of Jarkas (2010). The researcher investigated the application of the learning curve model to reinforcement bar and formwork labour productivity of building floors and found little evidence in the productivity. The study further mentioned four reasons to support their findings: the nature of the formwork/rebar operations, distinction between productivity improvement due to "trade learning" and "site acquaintance", psychological effect and the influence of learning that may have been overshadowed by other project-related and/or human factors (e.g. change in working methods). However, the factors that may have affected G1601 and G1602 learning rate are crew composition, inadequate knowledge in workmanship and construction method (e.g. variation in blockwork course arrangement: variability in wall stiffener, variability in wall joints, variation in blockwork re-bar and variability of wall columns).

The overall learning rate found in Figure 1 and Table IV shows a significant learning rate of 94.21 per cent. These craft gangs' significant learning in this project could be attributed to the craft gangs' composition of gangs' members, adequate knowledge in workmanship and experience in construction method. The overall learning rate found in this study concurs with the study carried out by Couto and Teixeira (2005) and observed a significant rate of learning not less than 85 per cent. However, these findings contradicted the findings of Jarkas (2010) on the application of the LCT to rebar-fixing labour productivity and observed that majority of buildings investigated exhibited either an increase or a negligible reduction in labour inputs as the cycle number of recurring floors increased (Figure 2). Furthermore, these findings support the findings of Long *et al.* (2013) on the relationship between building floor and labour productivity of structural work adopting the application of LCT and found that formwork labour productivity increased significantly in the construction. Thomas *et al.* (1986) stated that labour inputs are expected to decrease by a certain percentage as cycle numbers of work activity increases, these results extend these findings. The overall learning rates found in this study are in a relationship with the findings from previous researches in Vietnam, UK, Kuwait, Zimbabwean and USA (Jarkas, 2010, 2012; Long *et al.*, 2013; Thomas *et al.*, 1986; Couto and Teixeira, 2005).

Conclusion

Construction labour productivity has become one of the major concerns in the building industry, as it is generally labour-demanded and enhancing the performance of labour in the construction industry will improve the productivity in the construction industry. An understanding of the importance of on-site craft gangs' learning would provide insight into its impact

WORK STUDY DATA COLLECTION FORM			
FIRM:		STUDY NO:	DATE:
GANG NO:		START TIME:	
NO. OF SKILLED:	NO. OF UNSKILLED:	FINISH TIME:	
NO. OF OPERATORS IN GANG:		TOTAL OBSERVED TIME:	
CONTRACT DURATION:		WALL THICKNESS: 100mm ☐	150mm ☐
TYPE OF BUILDING	BUNGALOW ☐	225mm ☐	OTHER… ☐
STOREY BUILDING ☐	OTHER… ☐	WALL HEIGHT	0-1.5m ☐
NO. OF FLOORS:		1.5m – 2.1m ☐	2.1m –3.0m ☐
WEATHER CONDITION:		Above 3.0m ☐	
		OBSERVER:	

ELEMENT DESCRIPTION	R	WR	OT	BT	AL	ST	REMARK
Discharge/Loading of material							
Mixing of mortar							
Laying of blocks							
Pointing							
Others (specify)							

R = RATING; WR = WATCH READING/CUMMULATIVE; OT = OBSERVED TIME; AL = ALLOWANCE; ST = STANDARD TIME; BT = BASIC TIME

Figure 2.
Observation sheet

on labour productivity. This paper reports the research that observed the productive time of seven craft gangs' blockwork construction in Nigeria and analysed the productive time input to determine the significance of the learning rate. The observed productive time input was analysed using the linear regression technique which is also known as the ordinary least square technique with the application of the learning curve model. Craft gangs' productivity time recorded input was used as the dependent variable for predicting the regression model.

The result shows an average learning rate of 94.21 per cent resulting in 5.79 per cent improvement in labour productivity. The empirical evidence shows that on-site craft gangs' learning offers the platform for enhancing labour productivity and contributes to improving productivity in the construction industry. Among the seven craft gangs observed, the summary shows significant learning rate. This finding contradicts the previous study of Jarkas (2010) on the investigation into the application of the learning curve model to reinforcement bar and formwork labour productivity of building floors that found little evidence in the productivity. However, this study supports the previous research carried out by Long *et al.* (2013) on the relationship between building floor and labour productivity of structural work adopting the application of LCT that found an increase in formwork construction labour productivity.

This study extends previous studies that investigated the application of the LCT in construction labour productivity. The overall significant learning rate found in this study is related to the findings from previous research studies in Vietnam, UK, Kuwait, Zimbabwe and USA. The factors that may have contributed to the significant learning rate that resulted in improvement in the observed craft gangs' blockwork productivity are as follows: crew composition, knowledge in workmanship and experienced in construction method (e.g. ability to deal with following issues: variation in blockwork course arrangement, variability in wall stiffener, variability in wall joints, variation in blockwork re-bar and variability of wall columns).

The strength of this research is its comprehensive investigation and the application of the LCT in investigating the impact of on-site craft gangs' blockwork learning on construction productivity. Although this research study focused on blockwork construction, applying other types of construction materials like concrete, formwork, tilling, rendering and reinforcement steel can also have a positive impact on improving construction productivity.

Construction supervisors, project managers and other industry practitioners can also introduce this method as an important tool in the planning stage of construction to fast track the effective utilisation of construction work and improve the construction labour productivity. This will enable clients and those in the supply chain access to a possible means of changing their methods and practices of improving productivity.

Due to the nature of the study and the research question, the observations of this research study were limited to FCDA on-going government office building located in Nigeria. The limitation of this scenario is that the results generated from this study may not be generalised. In addition, this research investigation was limited to straight or linear block walls due to the limited number of curved walls encountered during the observed project. It is recommended that the influence of curved block walls on craft gangs' labour productivity be investigated further.

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