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Objective Assessment of Students' Cognitive Learning Outcomes: A Plea for Quality Science Education Instrument

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Abstract
Science education instrument is one of the determinants of quality output in the production of scientists for technological emancipation of a nation. It provides feedback on learning for knowledge and skills acquisition towards award of a certificate of proficiency and competence. However, the rate of graduate unemployment had been on a steady increase over the last two decades. As a result of low quality of certificated outputs. Therefore, the paper examines processes of constructing and validating a reliable instrument for measuring cognitive learning outcomes in science education in colleges of education in Nigeria. Also, it identifies features of a good question paper and marking guide/scheme as complementary components in the assessment of students' academic growth. Recommendations were made towards ensuring a valid and reliable quantification of students' cognitive achievement in science education.

Key words: *Assessment, , Instrument , Learning outcomes, Science education*

Introduction

The process of formal education starts with admission of prospective learners into a school setting at appropriate level. It terminates with either certification or non-graduation (compulsory withdrawal of studentship or voluntary through abscondment). The various stages involved in formal training are summarized in Fig.1.

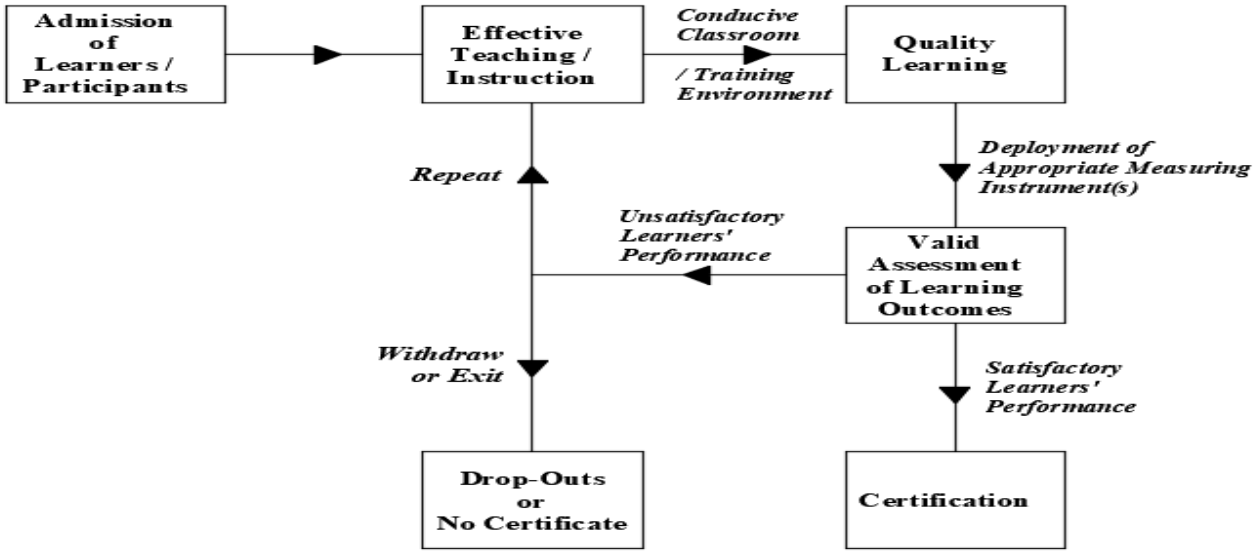

Figure 1: *A model of formal education process*

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Fig. 1 indicates that the critical decisions about suitability (fitness and readiness) or otherwise for the world of work are underpinned by validity of results obtained from assessment of learning outcomes. Such decisions may be one of the following: certification based on satisfactory performance, repetition of the training process or participant's withdrawal/abscondment as a result of unsatisfactory performance. It is expected that certificated individuals of educational institutions should be competent for direct absorption into the world of work or with minimal orientation for take-off. However, education in Nigeria was observed by Balogun (2012) to be devoid of standard, quality and functionality. This is reflected in the un-employability of university graduates in the country. It has led to persistent rise in unemployment rate as contained in Table 1.

Table 1: *Quarterly unemployment rate in Nigeria (2016-2020)*

Year	2016				2017				2018				2020			
Quarter	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Rate	12.02	13.32	13.38	14.29	14.44	16.18	18.8	20.42	21.83	22.73	23.13	NA	NA	27.1	NA	33.28

Source: *Sasu (Feb. 1, 2022*) *NA means Not Available

Table 1 revealed a consistent increase in the rate of unemployment in Nigeria between 2016 and 2020. An unemployed person was defined as an individual who is not doing any paid job. Un-employability of university graduates was trace to lack of generic and essential skills such as technical skills and competence in a chosen field, life skills like problem-solving and analytical skills, effective communication and literacy skills, interpersonal and team skills, etc (Abiodun-Oyebanji & Omojola, 2018). This was a product of absence of effective quality assurance mechanism in Nigeria universities. Quality assurance is concerned with proactive or preventive means of ensuring quality inputs, teaching-learning process, outcome and academic achievement of graduates (Anno, 2017). Volante-Yabut (2009) observed that the major aim of quality assurance is monitoring of performance in order to attain quality outputs. United Nations Educational, Scientific and Cultural Organisation, UNESCO (2002) identified five key components of quality assurance indicators as: what learners gain; quality learning environments; quality curriculum content; processes that support quality and outcomes from the learning environment. Other pointers to quality assurance as highlighted by Ehindero (2004) are: learners' behavioural characteristics, attributes and demographic factors; teacher's professional competencies/pedagogical skills; teaching processes, curriculum and learning environment as well as outcomes of education. However, the point of convergence of all quality assurance indicators/metrics is the need for objective evaluation and quality improvement (Abiodun-Oyebanji & Omojola, 2018).

The College of Education system is saddled with the responsibility to produce highly conscientious and well qualified teachers for Basic Education in Nigeria. This is implied in one of the goals of Teacher Education in the country: "...to provide teachers with intellectual and professional background adequate for their assignment…" (FRN, 2013:56). Thus, teacher production generally focusses on training personnel to acquire relevant competence in the following areas among others: correct interpretation of curriculum objectives for selection of appropriate and adequate contents, strategy for effective lesson delivery as well as assessment techniques. However, attainment of these lofty goals may become a mirage when assessment of students' academic progress (growth and development) is subjectively carried out with invalid instruments. Therefore, it is imperative to interrogate how objective assessment of teacher trainees could be achieved through selection, construction and deployment of quality instruments to measuring learning outcomes especially in science education.

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Learning outcomes

Learning outcomes, otherwise known as students' learning outcomes (SLOs) are descriptions of knowledge, skills and attitudes that students will acquire from participating in teaching-learning activities. Thus, they are known as learning objectives. They are usually expressed in clear, measurable statements using action verb(s). They abound for assignments, class, course, programme or institution. They link curriculum with assessment of students' learning outcomes.

Students' learning outcomes/objectives were grouped by Benjamin S. Bloomin 1956, into: cognitive, psychomotor rand affective domains. These are skills needed by learners in order to achieve educational goals/tasks in each of the three broad domains of learning objectives. Benjamin S. Bloom and Robert Mills Gagne provided further classifications of cognitive learning outcomes, Elizabeth Simpson for psychomotor and David R. Krathwohl for affective. However, Lorin Anderson and David R. Krathwohl revised Bloom' taxonomy in 2001. Table 2 shows relationship between learning outcomes and inherent skills.

Table 2: Relationship between learning objectives/outcomes and inherent skills

S/N	Learning Outcomes	Inherent Skills				
		Gagne (1985)	**Bloom (1956)**	**Anderson and Krathwohl (2001)**	**Simpson (1972)**	**Krathwohl (1964)**
1.	Cognitive	Intellectual skills	Knowledge, Comprehension, Application, Analysis, Synthesis, Assessment	Remembering, Understanding, Applying, Analysing, Evaluating, Creating		
		Cognitive strategy				
		Verbal information				
2.	Psychomotor	Motor skills			Perception, Set, Guided response, Mechanism, Complex overt response, Adaptation, Origination	
3.	Affective					Receiving, Responding, Valuing, Organisation, Characterisation

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Assessment of students' learning outcomes

Assessment of SLOs involves measurement, reporting and interpretation of students' academic growth (learning) and development. It is useful in the following ways:

i. To ascertain knowledge and skills gained/acquired by the students. The purpose might be for certification or remediation.
ii. To certify students' knowledge and skills' proficiency thereby giving assurance of learners' readiness for employment.
iii. To determine students' future learning needs i.e. placement.
iv. To predict performances of students on future leaning tasks i.e. prediction.
v. It advertises the character of an institution and its educational programmes (Coates & Richardson, 2012).

Assessment of SLOs encompasses formative or summative processes depending on the frequency at which it takes place and the purpose it is intended to serve. Formative assessment occurs more frequently than summative. It is usually carried out to diagnose students' area(s) of learning difficulty, the ultimate goal being remediation. Summative assessment is conducted most often for placement (promotion to next higher level of learning) and certification. Assessment of SLOs takes place in formal and/or informal settings. Formal assessment is the establishment of the quality of individual learning (Coates, 2015). Thus, attempts have been made to dissect assessment of students' cognitive learning outcomes with particular reference to acquisition of intellectual skills.

Developing objective and quality assessment instrument in science education

Learning outcomes play a significant role in linking science curriculum with assessment of SLOs. They are usually measured with the aid of assessment instrument(s). Thus, selection and construction of appropriate assessment instrument(s) depend largely on the contents of instruction/teaching/course of study which were carefully drawn in agreement with SLOs. Fig. 2 shows an interplay stage in the construction and validation of measuring instrument for objective assessment of SLOs in science education.

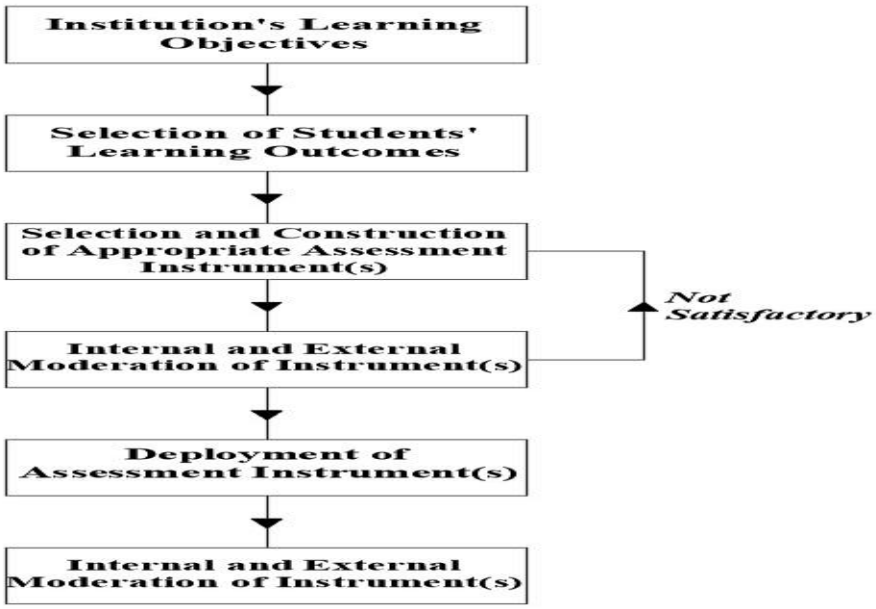

Figure 2 :A model for construction and validation of assessment instrument

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An assessment instrument is a measuring device used to quantify behavior. It comprises a set of stimuli presented to an individual in order to elicit response(s) on the basis of which numerical score(s) can be assigned according to predetermined rule(s) (Ary et al., 1979; Ayodele, 2010). The stimuli are questions to be answered by the students and the predetermined rules are contained on the marking guide/scheme. The students are referred to as testes or examinees and the stimuli/questions known as test/examination items. Assessment instruments may take one or more of the following formats: essay, short-structured essay, supply response/ fill-in the gap or objective (Ogunkunle, 2012). However, the purpose which the assessment scores would serve determine the format. Not with standing, essay and/or objective type of assessment instruments had been prescribed for use in Nigeria colleges of education (FRN/NCCE, 2020). Assessment of SLOs are usually undertaken on a continuous basis and at the end of a semester in colleges of education in Nigeria (FRN/NCCE, 2020). According to 2020 special edition of "Curriculum Implementation Framework for Nigeria Certificate in Education", total weights of 40% and 60% of the 100% marks obtainable in every course have been approved for continuous assessment (C.A.) and examination respectively by the National Commission for Colleges of Education (p. 59). Thus, C.A. instruments should take cognisance of fair distribution of questions across various levels on taxonomy of learning outcomes/objectives. This will prepare students adequately for excellent performance in the semester examinations which items are usually selected based on the same considerations.

Construction of an objective, reliable and valid assessment instrument starts with development of a test plan, blueprint or a table of specification (Ojerinde, 2011). The table of specification ensures equitable representation of various aspects/components of the learning contents (i.e. topics) and learning outcomes on the instrument. It is a two-dimensional table which shows learning outcomes as its columns and contents as its rows. A template for the table of specification is proposed in Table 3.

Table 3: Template for a table of specification

Contents	**Cognitive learning outcomes/objectives**						**Total**
	1 Remembering	**2 Understanding**	**3 Applying**	**4 Analysing**	**5 Evaluating**	**6 Creating**	
Topic 1							
Topic 2							
Topic 3							
Topic 4							
Topic 5							
Total							

The use of Table 2 is illustrated in the example below.

Example: Construct a table of specification for an objective test with 50 items in a 2-unit course which has 30 contact hours of teaching and 10 topics.

Solution

Step 1: Total number of test items required = 50 (100%).

Step 2: Determine the proportion/percentage of items for each learning outcome.
Let Remember = 40%; Understanding = 20%; Applying = 15%; Analysing = 10%; Evaluating = 10% and Creating = 5%.

Step 3: Total number of topics = 10

Step 4: Determine the time that will be spent on teaching each topic. Let contact hours for teaching be as indicated in Table 3.

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Step 5: Calculate the proportion/percentage of items for each content area using the time that will be spent on teaching it in relation to the total time (30hours in this case) which will be spent on teaching all the content areas.

Table 4: *Contact hours for teaching and associated proportion/percentage*

Topic	**Contact hours**	**Proportion/Percentage of items**	**Adjusted Proportion/Percentage**
1.	2	2/30 x 100 = 6.6	7
2.	4	4/30 x 100 =13.3	13
3.	4	4/30 x 100 =13.3	13
4.	4	4/30 x 100 =13.3	13
5.	2	2/30 x 100 = 6.6	7
6.	2	2/30 x 100 = 6.6	7
7.	4	4/30 x 100 =13.3	13
8.	4	4/30 x 100 =13.3	13
9.	2	2/30 x 100 = 6.6	7
10.	2	2/30 x 100 = 6.6	7
Total	**30**		**100**

Step 6: Find the **column total** using (proportion/percentage of learning outcomes) x (grand total) and **row total** with (proportion/percentage of contents) x (grand total).

Apply your discretion to round up or down.

Step 7: Compute the number of test items for each topic in each of the learning outcomes using either: (row proportion/percentage) x (column total) or (column proportion/percentage) x (row total). Use your discretion to round up or down.

Table 5: Number of questions by topics and cognitive learning outcomes

Content area/Topic	**Cognitive learning/objectives**						**Total (100%)**
	1	**2**	**3**	**4**	**5**	**6**	
	40%	**20%**	**15%**	**10%**	**10%**	**5%**	
1 (7%)	1.4 (1)	0.7 (1)	0.525 (1)	0.35 (1)	0.35 (0)	0.175 (0)	3.5 (4)
2 (13%)	2.6 (3)	1.3 (1)	0.975 (1)	0.65 (1)	0.65 (1)	0.325 (0)	6.5 (7)
3 (13%)	2.6 (3)	1.3 (1)	0.975 (1)	0.65 (1)	0.65 (1)	0.325 (0)	6.5 (7)
4 (13%)	2.6 (3)	1.3 (1)	0.975 (1)	0.65 (1)	0.65 (1)	0.325 (0)	6.5 (7)
5 (7%)	1.4 (1)	0.7 (1)	0.525 (1)	0.35 (0)	0.35 (0)	0.175 (1)	3.5 (4)
6 (7%)	1.4 (1)	0.7 (1)	0.525 (0)	0.35 (0)	0.35 (1)	0.175 (0)	3.5 (3)
7 (13%)	2.6 (3)	1.3 (1)	0.975 (1)	0.65 (1)	0.65 (0)	0.325 (0)	6.5 (6)
8 (13%)	2.6 (3)	1.3 (1)	0.975 (1)	0.65 (0)	0.65 (1)	0.325 (0)	6.5 (6)
9 (7%)	1.4 (1)	0.7 (1)	0.525 (0)	0.35 (0)	0.35 (0)	0.175 (1)	3.5 (3)
10 (7%)	1.4 (1)	0.7 (1)	0.525 (0)	0.35 (0)	0.35 (0)	0.175 (1)	3.5 (3)
Total (100%)	**20**	**10**	**7.5 (7)**	**5**	**5**	**2.5 (3)**	**50**

*Approximate values are contained on parentheses

Consideration for preparation of objective, reliable and valid questions in science education

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The following points must be considered when preparing assessment instrument (questions) which will be adjudged objective, reliable and valid in science education.

i. Decide on the test/examination format (essay, objective or a combination of both).
ii. Determine the time available to conduct the test/examination and the number of questions to put on the paper and answered by the students. For example, 2020 edition of "The Curriculum Implementation Framework for Nigeria Certificate in Education" stipulates the number of questions to be set and answered by the students as well as the duration of the paper for essay-type on page 63 and objective on page 64.

Table 6: Allocation of time and questions on essay paper by credit units

Credit units	Max. no. of questions set	No. of questions to be answered	Duration
1	3	2	1hr 30mins
2	5	3	2hrs
3	6	4	3hrs

Table 7: Allocation of time and questions on objective paper by credit units

Credit units	1	2	3
Minimum question items to be set	25	50	75
Duration	45mins	1hr	1hr 30mins

iii. Load essay questions according to:
   a. Learning outcomes using appropriate action verbs. Table 8 gives examples of action verbs associated with each level of learning outcomes on taxonomy provided by Anderson and Krathwohl (2001).

Table 8: Taxonomy of cognitive learning outcomes and associated ation verbs

S/N	Cognitivte learning outcomes	Associated action verbs
1.	Remembering	Define, identify, describe, rcognise, tell, explain, recite, memorise, illustrate, state, match, select, examine, list, locate, enumerate, record, quote, label, etc.
2.	Understanding	Summarise, interpret, classify, compare, contrast, infer, relate, extract, discuss, distinguish, predict, indicate, inquire, associate, explore, convert, etc.

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3.	Applying	Solve, change, relate,complete, use sketch, articulate, discover, transfer, show, demonstrate, produce, report, act, respond, prepare, manipulate, etc.
4.	Analysing	Contrast, connect, relate, devise, correlate, illustrate, conclude, categorise, deduce, devise, sub-divide, calculate, order, adapt, etc.
5.	Evaluating	Criticise, reframe, judge, defend, appraise, value, prioritise, support, decide, re-design, etc.
6.	Creating	Design, modify, role-play, develop, rewrite, pivot, collaborate, invent, write, formulate, imagine, etc.

b. Relative importance attached to each lerning content.
c. Time available to answer them.
d. Marks to be awarded.

Characteristics of a good science education question paper

A good science education question paper has the following characteristics among others.

i. Name of examination: institution, department, session/year, semester, course code and course title/subject.
ii. Rubrics: instructions on number of questions to answer by examinees/testes, time allowed/duration, information on where and how the questions should be answered.
iii. Unambiguously stated questions: questions should be stated using appropriate and clear language without ambiguity concerning the degree of accuracy expected in students' response, negative statements, extraneous clues and one item giving clues to in the statement of another.
iv. Some questions should contain hints on how they are to be solved/answered.
v. Good coverage of the learning outcomes through the use of a table of specification.

Features of a good marking guide/scheme in science education

Some features of a good science education marking guide/scheme include:

a. Name of examination: institution, department, session/year, semester, course code and course title/subject.
b. Rubrics: instructions on number of questions to answer by examinees/testes, time allowed/duration, information on where and how the questions should be answered.
c. Correct solutions to appropriate questions. These should include alternative answers to corresponding questions.
d. Adequate rewards and punishments for scoring responses adjudged to be solution(s) to relevant questions or otherwise respectively. For example, the National Commission for Colleges of Education in Nigeria prescribed 40% for continuous assessment and 60% for semester examinations (FRN/NNCE, 2020). These marks are to be proportionately distributed to solutions to questions on continuous assessment and examinationpapers respectively. It should be noted that weights attached to rsponses on marking guide/scheme should commensurate the amonut of information, their cognitive level on taxonomy of learning outcomes among others. For instance, responses to questions requesting students to define, state, list, mention, enumerate, highlight,among others should attract only 1mark each while those belonging to

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higher levels of cognition requiring them to explain and discuss (in which case the examinees would list/mention/define before providing more information) should be credited with at least 2marks (1mark and 1½marks for listing and definition respectively) for every correct effort. The remaining mark should be credited for additional information provided by the examinees. Such colud be example(s), unit(s) of measurement among others.Also, every main/major point in the desription of a phenomenon or an experiment should attract at least ½mark depending on the mark(s) available for the question and the total number of pionts expected in a complete description. Furthermore, diagram should attract marks for correct drawing and ½ or ¼mark for each labellingdepending on total marks available and items to be identified on it.

e. Reliable marking guide/scheme should produce least variations in grading of the same students' responses done/made at different times, locations and examiners/markers.

Validation of science education assessment instruments

An objective assessment of SLOs must satisfy two major criteria: it must be valid and reliable. Validity of a science education assessment instrument is the extent or degree to which it measures students' academic achievement (Ary et al., 1979; Kerlinger, 2000; Seweje, 2002). Reliability is the degree of consistency with which an instrument mesures students' academic achievement (Ary et al., 1979; Kerlinger, 2000; Kolawole, 2002). Validating a science education assessment instrument entails ensuring that it is valid and reliable within the context of the purpose for which it was constructed. The National Commission for Colleges of Education (NCCE) recommends internal and external moderation of NCE II and NCE III questions and marking guide/scheme by Head of Department (H.O.D.) and External Examiner appointed by the Academic Board of a college prior conduct of every semester examination while the exercise be repeated for marked scripts and scores post/after the examination (FRN/NCCE, 2020). This is to ensure objective assessment of students through the use of reliable and valid science education instruments. It is noteworthy that Heads of Department (HOD) is not usually below the rank of a Senior Lecturer while the External Examiner should be either a Principal or Chief Lecturer in relevant discipline.

Conclusion

The primary purpose of every teching/training session is to bring about a relatively permanent change in behaviour of participant(s). this can be ascertained through assessment of learning outcomes. The use of a quality science education instrument to measure and facilitate a comparison of the initial/entry and final behaviours of learners provides an objective information which aids a valid decision about academic growth and development of the the students. The insturment must contain test items which had been carefully selected to reflect learning outcomes and with the ability to discrimate/screen testes according to their relative achievements on the programme. Furthermore, science education marking guide/scheme must be able to reward examinees adequately for their learning efforts. Therefore, science education assessment is considered to be objective, reliable and valid when the scores peoduced are statistically significant.

Recommendations

The following recommendations are made for implementation.

1. Adequately qualified personnel should be appointed as external moderator.
2. There should be correct interpretation of course objectives as stated in the NCCE minimum standards in order to select appropriate contents for teaching.

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3. A well constructed table of specifications should be used to generate questions in unambiguous language and with sufficient information which can guide examinees to clear-cut response(s).
4. There should be strict adherence to the provisions of a good marking guide/scheme in order to reduce biases in grading of examinees' responses to questions.

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