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Sample Size and Sampling Techniques in Chemistry Education Research: A Meta-Synthesis

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Abstract

The rate at which chemistry education research beginners were picking sample from their research population without specific guidelines and sampling procedures as observed in many online journal articles is worrisome. This problem must not be overlooked, if competent scholars would be trained for the future generations. The rationale behind this study is to change the narrative as the field of chemistry education is growing into maturity. The study hereby aims to provide the chemistry teaching community, project students and postgraduate researchers, with empirical basis for sample size determination and sampling techniques utilizable in Chemistry Education Research (CER). The study, being a qualitative method and a meta-synthesis design to be specific, used journaling" to collect data from 50 articles published between the years 2018 and 2023. The study revealed sample size determinations options such as scholarly published tables including Krejcie and Morgan 1970 and Research advisor 2006, the sample size formulae including; the Bourley formula of 1964, the Cochran's formula of 1963 and the Taro Yamane's formula of 1967. Nevertheless, the sampling techniques found include, the snowball sampling, multistage sampling, cluster sampling and systematic sampling. In order to improve the quality of research findings in chemistry education, the study recommends that the research beginners should use most appropriate and well understood sampling techniques and sample size determination options in their research adventures.

Keywords: Chemistry Education Research, Sample Size Options, Sampling Techniques, Taro Yamane's Formula, Cochran Formula.

Introduction

The benefits of Chemicals have extended across a wide range of professions. This is not limited to the provision of pesticides, herbicides and fertilizers for the improvement of crop yield in Agricultural sector [1]. Chemistry contributes to improved health care services and sanitation through the provision of active ingredients for pharmaceutical drugs and recycling of wastes [2]. The practices of Chemistry knowledge have been witnessed in sports activities and in automobiles industries where recreational facilities such as ball, racket, bandage and iodine, vehicle seats, airbags, and tires are made available for man use. Extraction of bauxite, lime-stone, rubber and other raw materials for modern industries to boost the economy has benefitted in the effort of chemistry. In the security sector, Military has also experienced a tremendous growth in artillery through the application of chemical knowledge [3]. Chemistry has also been playing laudable roles in transportation by responding to the fuel needs of the industry like petrol, diesel, coals and jet fuel. Nevertheless, in higher education, secondary school chemistry is a prerequisite for the training of Science, Technology, Engineering and Mathematics (STEM) work-force.

These benefits have made the teaching and learning of Chemistry, a global desire for economic growth and global security. Therefore, Chemistry Education could be seen as a pseudo-scientific research field, dealing with the process of teaching and learning of chemistry through continuous interactions between, theories and practices [4]. As described in Babalola and Awaisu Chemistry education is a systematic process of imparting and acquiring fundamental knowledge of matters with which man can shape and reshape the world [5]. Technically, in Chemistry Education, the subject Chemistry is the scientific study of properties and behaviors of matter, the investigation of its compositions and reactions, and the use of such reactions in forming new substances [6]. It is a natural science dealing with substances ranging from the elements that make up matter to the compounds composed of atoms, molecules and ions [7]. The essence of Chemistry teaching is to ensure that learners are gaining adequate knowledge not only to pass examinations but also to face the future challenges of work-place and of life.

Chemistry students are expected to receive training which will enable them solves problems through transfer of knowledge from one context to another when engaged after graduation. As reported by Tilahun and Tirfu, the students who cannot achieve this basic indicator usually assessed through examinations are said to have performed poorly [8]. The challenges of poor performance in chemistry and the likes such as inadequate acquisition of vocational skill for self-reliance are all consequences of poor teaching techniques, poor learning habits and inadequate linkages between research and practice [9]. These obvious problems of Chemistry education need solutions from the chemistry teaching community including researchers. The solutions required, informed the systematic approach to problems solving known as the Chemistry Education Research in higher institutions.

Globally, higher institutions are post-secondary institutions with the primary functions of teaching, research and community services for the purpose of producing high level manpower and research findings required for industrial application to improve the economy. According to the National Policy on Education, University Education shall make optimum contributions to the national developmental goals by inculcate community spirit in the students, through projects and action research (FRN, 2014). They shall be encouraged to disseminate their research results to both government and industries. It is however imperative that Chemistry Education researchers and project students have relevant professional expertise in Chemistry Education Research.

Historically, Cooper and Stowe stated that the idea of Chemistry Education Research first came to existence in 1924 through the writing without references of W.A Patrick in the first issue of the Journal of Chemical Education (JCE) where he raised a question of what kind of research is essential to good teaching of chemistry [10]. He later resolved that the research work in chemistry teaching should be characterized by combing chemistry from end to end for facts and for methods of exposition that will make such facts lively and real to students. The chemistry education literature in the early 20th century was of a kind with Patrick's piece which consisted largely of opinion and laboratory exercises without references.

Chemistry Education Research (CER) is the study of how one or more independent chemistry education variables influence, predict, impact or affect the dependent variables. The variables of CER includes, teaching methods, learning habits, chemistry laboratory, teachers' qualification, students' perception, interest, retention, attitudes, self-efficacy, conceptual understanding, misconception, learning styles, and academic achievement, to mention but a few. As described by the Jensen, research in chemistry education focuses on understanding how students learn chemistry, how best to teach chemistry and how to improve learning outcomes by changing teaching methods [11]. Therefore, CER studies how small group active learning strategies and laboratory investigations impact student learning.

In practice, CER utilizes quantitative, qualitative or mixed method of data collection to upgrade not only the students learning skill but also that of teachers' teaching skills. Quantitative methods are; Descriptive survey design, Correlation design, Causal-comparative design, Experimental design and quasi-experimental designs typically involving collection of data that can be analyzed using various statistical methods. Qualitative methods such as phenomenological study, case study, ethnographic study, and grounded theory, meta-synthesis and action research use interviews, observations, journaling, and other methods of data collection. CER is more aligned with the social sciences in that the systems being studied are composed of human behaviors in relation to intelligence and skills acquisitions rather than the study of molecules, atoms, mass, ions and particles as obtained in pure chemistry. Therefore, CER focuses on how students learn about the behavior of atoms and molecules rather than directly studying the atoms and molecules. So, the theories, methodologies, and data collection instruments used in CER differs from those utilized in the traditional chemistry research. Hence, Bounce & Cole describes CER as one of the "Discipline-Based Education Research (DBER) in the areas of student conceptual understanding, technology assisted learning, analysis of student discourse, argumentation patterns, and the development of assessment tools to measure student thinking [12]. Consequently, CER has become an essential component of Chemistry Education Scheme at the tertiary institution level with undergraduate students doing "Research Project" while the post-graduates ones are to present their research reports in form of Dissertations and Theses as part of the requirement for the award of degrees.

Whatever the nomenclature given to CER, the essence is to bring end to end solutions to specific problems confronting the teaching, learning and vocational training in Chemistry so as to motivate more students into the Science disciplines. CER is a systematic endeavor which cannot be done haphazardly; it must be thorough as obtainable in Social Sciences. The reason being that, any margin of error above 0.05 in its findings may jeopardize the theory and practice of Chemistry Education in schools, colleges and in the application of chemical knowledge in our day-to-day life activities. Unfortunately, one of the sources of type1 and type 11 errors, where the supposed rejected hypothesis are accepted and vice versa is the sample size determination. This is as bad as saying the worst teaching method for chemistry is the best method. Therefore, possible sources of error such as inadequate sample size or the use of unmanageable sample size must be properly checkmated in CER. This can easily be achieved through application of the right choices of sample size in CER.

Sample size means a fraction of the study population selected to represent and upon which the fate of the entire research population is to be judged. Lawrie viewed Sample' size as the number of participants selected to represent a larger population in the context of the study [13]. As reported by Kibuacha, it is the basis upon which the findings made would be generalized on the entire population [14]. The implication of not sourcing correct sample size in CER is similar to testing just five elements on the periodic table and concluded that all elements in the periodic table are halogens. Therefore, to be fair and just in CER findings, adequate sample size is necessary. Nevertheless, a professional chemistry education researcher cannot just pick a large chunk of the population and assume justice has been done to the entire population. This is because, financial constraints and time factor are sacrosanct in picking only the required sample, which is one of the important rationales for this study.

Nevertheless, sample size determination Options are approaches in chemistry education research which enable chemistry education researchers to select only the fraction of the entire population required to yield the expected result as findings which could be generalized on the entire population without bias, at the minimum cost and time. Examples of samples size determination options include; Social Researchers Workers Option; Available Sample Size Option; Volunteer Sample Size option; Population-turned Sample Size Option; Literature Review Option; Sample Size Formula Option and Published Tables of Sample Size Option. These sample size determination options enable researchers to know the fraction of study population needed and this can be easily extracted from the target population using the chosen sampling techniques.

Sampling techniques are the procedures involved in drawing the required sample size from the entire population. This is usually done through the use of either probabilistic or non-probabilistic sampling techniques. Probability sampling is a technique in which the researcher chooses samples from a larger population using a method based on probability theory. It is based on the fact that every member of a population has a known and equal chance of being selected. Examples of Probability sampling approach are simple random sampling, systematic sampling, stratified sampling, and cluster sampling. Conversely, non-probabilistic sampling techniques are less stringent sampling technique in which the researcher selects samples based on the subjective judgment of the researcher rather than random selection.

Research Problem

Generally, the computation of the appropriate sample size and the choice of sampling techniques in Chemical Education Research are considered to be one of the most important steps in quantitative study. But it is observed that most of the beginners Chemistry Education researches, found this particular step difficult as the experts often concentrate on qualitative studies where such steps are often been overlooked. In quantitative research, the sample size computation must be done appropriately in that if the sample size is insufficient the inference drawn from the sample will not be authentic and it might lead to some wrong conclusions. Similarly, when we draw inference about parameter from statistical analysis, some kind of error arises. The error which arises due to a sample being used to estimate the population parameters is called the sampling fluctuation. No matter the degree of cautiousness in sample selection procedure, there will always be a difference between the parameter and its corresponding estimate. A sample with the smallest sampling error will always be considered a good representative of the population. Nevertheless, bigger sample sizes have lesser sampling errors but smaller sample sizes are easier to manage, have less non-sampling error and less expensive.

Similarly, sampling techniques is another problematic area often overlooked in many chemical education researches which needs proper attention by this subject based discipline scholars. A wrong sampling technique is hereby another problem considered in this study in that a wrong choice of sampling techniques will surely lead to a wrong sample which is the representative of the entire population. For instance, it will be wrong to conclude that all the elements on the periodic table are halogen due to wrong sampling techniques which produced members of the halogen's groups like Fluorine, Chlorine, Bromine, Iodine and Astatine as a study sample.

Research Questions of the Study

1. What are the most predominantly used samples size determination options in chemistry education research between the years 2018 and 2023?
2. What are the most predominantly used sampling techniques in chemistry education research between the years 2018 and 2023?
3. What are the factors that influence the choice of sample size determination options in Chemistry education research between the years 2018 and 2023?
4. Are there any factors that influence the choice of sampling techniques used in chemistry education research between the years 2018 and 2023?

Research Methodology

This study aims to provide young chemistry education researchers with an empirical basis for sample size determination choices and sampling techniques required in Chemistry Education Research (CER). The study is a qualitative methodology and a meta-synthesis design to be specific using journaling data collection approach. The chemistry education research articles published between the years 2018-2023 made available on the global space formed the study population. Three hundred and twenty (320) Chemistry education research Journal articles published between the years 2018-2023 on secondary schools were used as the study sample.

Results of the Study

Q1: What are the most predominantly used samples size determination options in chemistry education research between the years 2018 and 2023?

The most predominantly used samples size determination options in chemistry education research between the years 2018 and 2023 are presented below;

1. Volunteer Sample Size Techniques Option

This is a type of sample size determination in which the number of respondents' subject who willingly submitted themselves to be used as sample is selected. This kind of approach is suitable in a situation where access is denied to the population. For instance, Muslim women in so many countries including the Northern part of Nigeria are not allowed to be interviewed without the permission of their husbands, the number of women permitted by their husbands and willingly submitted themselves to participate in a study becomes the sample size of the study especially in a case where the study population covers Science/chemistry Students' parents and guidance. Also, in a school, even when using intact class in a quasi-experimental design research, only the students' who willingly submitted themselves to take achievement pre-test or post-test or not absent on the day the test was administered become the study sample.

2. Social Researchers Workers Technique Option

The Social Researcher Workers Techniques Option (SRWTO) is summarized in the table1;

Table1: Social Researchers Workers' percentage of Population Recommended as sample

s/n	Specification	Population	Sample Size required from Population
1	Few hundreds	100-500 people	40% of
2	Several hundreds	600-900 people	30%
3	Few thousands	1000-5000 people	10%
4	Several thousands	Greater than 5000 people	5%

Source: Computed from the statement of Kpee [15].

As summarized in table1, this approach states that, if the population of a study is a few hundreds, 40% of the population will serve as acceptable sample [15]. However, if the population is many hundreds, 30% of the population will do, but if the population is a few thousands, 10% of the population will do but if several thousands, 5% of the population will be ok. This approach assumes that the suggested percentage will be fairer representations of the entire population.

Take as an example, if the population of Chemistry Education students in the Department of Science Education, Yusuf Maitama Sule University Kano is 667. The sample size could be calculated as; if the study population is several hundred, 30% of the population is required. Therefore, (667 x 30%) = (667x0.30) = 200students are the required sample size.

Similarly, if the students' population in the Department increased to 9000-students, the sample size will become; several thousand= (9000 x 5%) =(9000x0.05) =450students is the study sample.

3. Literature Review Technique Option

In this approach, the researcher used other sample size that other researchers in the literature reviewed, used. Therefore, the sample size used by other researchers in the similar study is considered the appropriate sample size for the new study. An example of this is Israel (2005) who proposed 25% of the study population to be used as sample size in a social science research.

4. Intact Class Technique Option

In this approach of determining sample size, the number of students available in the classes chosen becomes the sample size of the study population. In this case the study sample might be taken as the class size while the study population is the number of students in the school.

5. Population Turned Sample Size Technique Option

This approach takes effect whenever the population of the study is not too big to be used as the study sample after considering the cost and time available for data collection. Hence, the entire population becomes the sample. For instance, this sample size determination technique option becomes the most appropriate if the number of Chemistry teachers in a local Government of study is less than 200. It can also be used for sample size, when the number of science students in a class which serves as population is less than 100, which is manageable.

6. Published Table of Sample Size Determination Option

This involves the use of table of sample sizes given by research experts. Examples of such table of sample size determination include; Krejcie and Morgan (1970) and Research Advisors (2006). For better comprehension, the tables are available online. The tables usually married the population of the study with the expected or recommended sample size of the study. However, the researchers in this case are at liberty to choose a bigger sample size but not lesser.

7. Formulae of Sample Size Determination Option

Formulae of sample size determination options are tested and trusted products of expert research findings gotten through the use of research parameters such as standard error and degree of freedom. Examples of formulae of sample size determination techniques option are as follows;

a) Taro Yamane's formula of Sample Size Determination, 1967

The Taro Yamane's sample size determination formula is given by $\{n = N/1+N\alpha^2\}$.

Where; n= Sample Size;

N= given population and

α = Significant level of error usually 0.05 (95% confidence level and p=0.5).

Take for instance; if the population of chemistry education students in Yusuf Maitama Sule University, Kano is 1260-students. Then, the sample size could be calculated as;

$n = N/(1+N*\alpha^2) = 1260/1+1260(0.05)^2 = 1260/1+1260 \times 0.0025) = 1260/4.15 =$ **304-students.**

b) Cochran Formula of Sample Size Determination, 1963

There is a sense of similarity between the Cochran Formula and that of Yamane (1967) earlier discussed. American International University, explained that Taro Yamane's formula is used when the population is small while the Cochran formula of 1963 is considered particularly appropriate in large populations [16]. Cochran formula allows researchers to calculate ideal sample size given a desired level of precision, desired confidence level, and the estimated proportion of the attribute present in the population. The Cochran formula for a known population (finite population) "N" is given by n= no/ (1+ (no-1)/N. Where; no =Cochran's value= $(Z^2Pq)/e^2$

N=Population; n=new adjusted sample size.

e=margin of error (0.05)

p=maximum variability usually taken as 0.5, q=1-p=0.5; Z= Z-table value.

Let's assume a researcher is to conduct a research on Chemistry students all over the world and want to find out how many students read daily. Since, the researcher does not have much information on the subject, the researcher is going to assume that half of the students take read daily which gives the researcher maximum variability p = 0.5. If the researcher wants 95%

confidence, and at + or -5% precision (margin of error or confidence interval). However, from the normal table of Z-Score, the confidence level needs to be turned into a Z-score. Here are the Z-scores for the most common confidence levels:

- 95% – Z Score = 1.96 (Expected for human population in Chemistry Education research)
- 99% – Z Score = 2.576 (Expected for Chemical population in Chemistry Research)

Hereby, since the students are humans, 95% confidence level which means (e=0.05) is the appropriate and the Z-value required is 1.96, so by using the Cochran's formula

no = $[Z^2Pq]/e^2$, the researcher will get

no =$[(1.96)^2 (0.5) (0.5)] / (0.05)2 = 385$.

The value of no for chemistry education research and other social sciences with 95% confidence level should always be taken as 385 while using the Cochran formula (n= no/ (1+ (n_o-1)/N) where "N" is the study population. Let's imagine the study population is known to be 800. Hence, the required sample size could be calculated as follows;

n= n_o/ (1+ (n_o-1)/N=385/1+ (385-1)/800=385/1+(384/800) =385/1+0.48=385/1.48= 260-Students

Nevertheless, in a situation where the study population is unknown/uncountable, the Cochran sample size (n_o=385) will serve as the required study sample (385-students will be sample size).

c) Bourley's formula of Sample Size Determination, 1964

This is a population allocation formula most suitable for stratified sampling techniques. The Bourley's formula as given by American international University (2020) is; nh = nNh/N.

Where; nh = sample size per each group

n=the total sample size;

Nh =Number of people in each group and

N=Total study population

As an example, in Yusuf Maitama Sule University, Kano, just like any other great Universities in its category in the world such as Harvard University, the chemistry education students' population could be stratified into; Above Average, Average and Below average. Using the Bourley's formula; if the total sample size for the research is 272, therefore n=272; the total population of students is N=854 and the total number of Above Average students Nh =6. Therefore, the composition of the Above Average needed in the entire sample to be drawn from the population can be calculated thus;

nh = n (Nh)/N

=272(6)/854

=2 (2 students in the Above Average echelon required)

Therefore, 2 students in the Above Average category in terms of Intelligent Quotient (IQ) in the University will be needed to participate in the sample to be drawn from the entire population of the University. However, if the Average Students in the entire university is 200, then,

nh = n (Nh)/N

= 272(200)/854

= 64 (Approximately, 64-Average students will be needed)

Similarly, if the number of Below Average students in the University are 648, then,

nh= n (Nh)/N

= 272(648)/854

= 206.38 (Approximately, 206-Below Average students will be needed)

This means by approximation 206-Below Average students in term of intelligent quotient in the University must be part of the sample needed.

Q2: The predominantly used sampling techniques in chemistry education research are probabilistic sampling techniques. These are techniques in which the researcher chooses samples from a larger population through a method based on probability theory. Every member of the population has equal chance to be selected. The most predominant Probabilistic sampling techniques found between the years 2018 and 2023 are;

1. **Simple Random Sampling:** This is a probability sampling type in which the researchers randomly choose the sample in a way that each member of the population has an equal chance of being selected.
2. **Systematic Random Sampling:** This is another type of probability sampling where researchers select members of the population at a regular interval after numbering them. For instance, a researcher may which to select only the even numbered participant of the population as sample.
3. **Stratified Random Sampling:** In this case, the researchers divide the population into subgroups/strata based on shared characteristics like gender, educational qualification, socio-economic background and members of each stratum are randomly selected until the sample size is attained.
4. **Cluster Sampling:** Cluster sampling is a probability sampling technique often used to study large populations spread across a wide area where the researchers divide a population into clusters and randomly select one or more clusters to form the sample.
5. **Multistage Sampling:** This is a probability sampling technique used to collect data from a large, geographically spread of people group such as in national surveys, where the researchers draw sample from a population by picking smaller and smaller units at each stage until the required sample size is attained.

Conversely, non- probabilistic sampling is less stringent sampling technique in which the researcher selects samples based on the subjective judgment of the researcher rather than random selection. The few non-probabilistic sampling techniques found in the chemical education literature are;

1. **Convenience Sampling:** This is a non-probability sampling technique involving respondents who are conveniently accessible to the researcher. For example, a researcher from Yusuf Maitama Sule University, Kano who is working on assessment of Chemistry teachers' quality may enter any science college, Kano and ask for Chemistry teachers who are Alumni member of the university to participate in the sample.
2. **Volunteer Sampling:** In this case, researchers seek volunteers in person, over the internet, through public postings, and a variety of other methods to participate in studies.
3. **Judgment/Purposive/ Authoritative Sampling:** This is a non-probability sampling where sample members are selected on the basis of researcher's knowledge and judgment.

4. **Quota Sampling:** This is a situation in which the Researchers choose sample according to specific traits or qualities involving individuals that represent a population.
5. **Intact Class Sampling:** This is a non-probability sampling technique in which the researcher used already-formed group like a classroom of students or an industry or a museum to produce sample that can be generalized through rigid assumptions.
6. **Snowball Sampling:** This is a non-probability sampling technique in which an already identified member of the sample refer the researcher to another member and the new member refer the researcher to another until the required population size is attained. It is used to source sample from people with specific characteristics difficult to identify.
7. **Crowd Sourcing Sampling:** This is a survey method where the researchers obtained information or opinions from people via the Internet, social media and smart phone apps.
8. **Web Panels Sampling:** This is also a survey method utilizing samples from web panels that are willing to participate in such surveys.
9. **Accidental /Grab or Opportunity Sampling:** This is a form of non-probability sampling that utilizes handy member of the population as sample, rather than careful determination.

Q3: The factors which determined the sample size options in chemistry education research between the years 2018 and 2023 are;

a. **The Level of Precision**

Degree of precision is the margin of permissible error between the estimated value and the population value. It is the measure of how close an estimate is to the actual characteristic in the population. The level of precision may be termed as sampling error. The precision desired may be made by giving the amount of errors the researcher is willing to tolerate in the sample estimates. The difference between the sample parameter and the population parameter is called the sampling error. This depends on the amount of risk a researcher is willing to accept while using the data to make decisions. It is often expressed in percentage. If the sampling error or margin of error is ±5%, and 70% unit in the sample attribute some criteria, then it can be concluded that 65% to 75% of units in the population have attributed that criteria. High level of precision requires larger sample sizes and higher cost to achieve.

b. **The Confidence Level**

The confidence or risk level is ascertained through the well-established probability model called the normal distribution and an associated theorem called the Central Limit theorem.

c. **The Degree of Variability**

The degree of variability in the attributes being measured refers to the distribution of attributes in the population. The more heterogeneous a population, the larger the sample size required to be, to obtain a given level of precision. For less variable (more homogeneous) population, smaller sample sizes work nicely. Note that a proportion of 50% indicates a greater level of variability than that of 20% or 80%. This is because 20% and 80% indicate that a large majority do not or do, respectively, have the attribute of interest. The proportion of 0.5 indicates the maximum variability in a population. It is often used in determining a more conservative sample size.

Q4: The factors that influence the choice of sampling techniques used in chemistry education research between the years 2018 and 2023 are expertise, duration of study/time factor, cost of sampling and accessibility to the target sample [17-22].

Conclusion

As earlier observed from the literature examined before venturing into this study that Chemistry Education Scholars seems to be picking sample from their study population without specifying their sampling techniques and the procedures used to determine the used sample size. This study further confirmed the reality of the situation. A large number of research articles in examined failed to mention sampling size determination choice and their sampling procedure. It appeared that majority of such articles used convenient and intact class sampling techniques. However, the sample size determination options and sampling techniques found are presented in this study. Also, the factors responsible for sample size determination and sampling techniques also listed.

Recommendation for the Improvement of Chemistry Education Research

The following are the recommendations made to improve the sampling techniques use, sample size determination options and the quality of Chemistry Education Research on the global space.

1. Chemistry Education researchers should familiarize themselves with the available sample size determination options in Chemistry education research found in this study.
2. Chemistry Education project supervisors should endeavor to introduce their project students to all available sample size determination options and sampling techniques.
3. The most suitable sample size determination based on the available parameters such as population size, nature of sample, level of significance, and other describable parameters should be used by the Chemistry Education researcher and project students.
4. Chemistry Education researchers are encouraged to check other researchers' work online to determine the most common method of sample size used in similar researches.
5. Chemistry researchers are advised to assess the sample size determination techniques used in online published articles to determine the quality of Chemistry education research, projects and articles available in the global space for public consumption

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