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Development and Factorial Validation of Meta-Cognitive Awareness Inventory in Physics (MAIP) for Senior Secondary School Students in Benue State, Nigeria

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Abstract

Purpose: The study developed and factorial validated of Meta-cognitive Awareness Inventory in Physics (MAIP) for senior secondary school students in Benue State, Nigeria. Three research questions and one null hypothesis guided the study. **Methodology:** The study adopted instrumentation design. The sample comprised 1382 SSII students that offered Physics as a school subject for 2020/2021 Academic Session. The Meta-cognitive Awareness Inventory in Physics (MAIP) was face validated by five experts. Construct validation was carried out on the instrument. Coefficient of internal consistency was obtained through Cronbach's Alpha and found to be 0.78. The research questions were answered using factor analysis, coefficient of internal consistency, mean and standard deviations. The null hypothesis was tested using independent t-test at 0.05 level of significance. **Findings:** The findings revealed that MAIP has 52 factorially simple or pure items and 23 factorially complex items in terms of their factor loadings. The coefficient of internal consistency of MAIP was found to be 0.98. It was also found that there was statistically significant difference in the mean meta-cognitive awareness ratings of students in rural and urban areas in favour of students in urban area using MAIP**. Signifinance:** It was recommended among others that Senior Secondary students should use the MAIP to determine their level of meta-cognitive awareness in Physics in both urban and rural schools. This may enable them to gain awareness and control over themselves as learners for effective learning of Physics in secondary schools irrespective of their locations.

Keywords: construct validity, meta-cognitive awareness, reliability, school location, usability.

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Introduction

Meta-cognition plays an important role in the learning of physics because, it may help students to be capable of planning, monitoring and evaluating how much learning is effective. It can answer questions related to the development in cognitive and affective areas. Meta-cognition also, has been described as one's ability to know and regulate cognitive processes, calibrate or monitor one's performance and chart learning plans based on learning and performance estimate and what we know about our cognitive processes and how we use these processes in order to learn and remember (Salari et al., 2013). Meta-cognition also enables students to solve new problem by retrieving and deploying strategies that they have learnt with reference to similar context (Ozturk, 2017). Therefore, to help students learn physics effectively, teachers need to enhance their students' use of meta-cognition so that they gain control and awareness over themselves as learners. Meta-cognitive awareness is a crucial factor in the attainment of a reasonable academic excellence. Meta-cognitive awareness is the personal understanding of one's cognitive and affective state and how to specify conscious thinking of one's own learning. The impact of meta-cognitive awareness on students' academic achievement was found to be statistically significant (Mohammed, 2015; Dogra, 2016; Aurah, 2018). However, Yilmaz & Yalcin (2012) found that students' success levels do not reflect their knowledge levels, that students experienced some problems while converting procedural knowledge into declarative knowledge and due to the problem, they failed to understand Newton's laws of motion adequately. Students are unable to solve non-routine physics problems due to low meta-cognitive awareness.

In order to measure meta-cognition, Meta-cognitive Awareness Inventory (MAI) developed by Schraw & Dennison (1994) and Junior Meta-cognitive Awareness Inventory (Jr.MAI) developed by Sperling et al. (2002) are widely used. They could be considered as domain general instruments rather than domain-specific instruments to physics. However, the domain-general or domain-specific issue in meta-cognitive awareness remains unsolved. With reference to the domain-specific property of meta-cognitive awareness, the development of meta-cognitive awareness inventory specific to physics becomes imperative.

The development of an instrument is the most important part of conducting a quality instrumentation or developmental research study. Developmental study takes cognizance of some salient steps. These are content outline, objective of the instrument, construction of items, face validation, item selection, trial testing, item analysis, reliability of the instrument, item selection, norming, inventory manual, final production and marketing of the inventory and its manual among others (Emaikwu, 2011; Nworgu, 2015). Therefore, development and factorial validation of Meta-cognitive Awareness Inventory in Physics (MAIP) for Senior Secondary school students in Benue State involved this number of steps beginning with content outline.

The content outline of the Meta-cognitive Awareness Inventory in Physics (MAIP) was prepared based on the components of meta-cognitive awareness. These are declarative, procedural and conditional knowledge. Others are planning, monitoring, evaluation, debugging, and information management. After the content outline, comes the objective of the instrument. The objective of the instrument was specified in order to develop a valid and reliable instrument and use the instrument base on school location. The items on the instrument are constructed to reflect the components of meta-cognitive awareness. The instrument was then submitted to experts for critiquing and weighting to ensure face validity. The criticisms, suggestions and inputs of the experts were articulated to produce a working instrument which was used for trial testing to generate data for item analysis and internal consistency.

Item analysis was carried out to establish the construct validity of Meta-cognitive Awareness Inventory in Physics (MAIP). Construct validation was done using factor analysis. Having executed the item analysis, the items that have satisfactory statistical qualities are selected for inclusion on the final form of the instrument. Then the instrument is assembled in the form that it should be. The assembly is based on the ease with which students can understand what to do, when and where to respond as well as the ease with which the researcher can locate and rate students' responses. The responses are used for the establishment of reliability index of the instrument. Having selected and assembled the inventory items, the next thing is to go for final testing by administering the inventory on a fairly large sample of students similar to those whom the inventory is intended (Nworgu, 2015). However, the present study would be limited to establishing the construct validity of Meta-cognitive Awareness Inventory in Physics (MAIP).

The validity of an instrument refers to the extent an instrument measures what it is designed to measure (Nworgu, 2015). Validity of an instrument is purpose dependent; this implies that, an instrument which is valid for one purpose may not be valid for another. For instance, construct validity is the extent to which a particular test can be shown to measure a hypothetical construct or trait (Nworgu, 2015; Emaikwu, 2019). It is also the purity with which an instrument measures any construct it is designed to measure. Establishing construct validity involves a statistical procedure called factor analysis.

Factor analysis is a mathematical procedure which can be used in describing certain areas of nature. According to Emaikwu (2011) factor analysis refers to a variety of statistical techniques whose common objective is to present a set of variables in terms of smaller number of hypothetical variables. The rationales for factor analysis are to investigate pattern of relationship to identify whether the correlation between a set of observed variables stem from their relationship to one or more variables in the data, analyze the structure of a phenomena and development of measurement scale which is Meta-cognitive Awareness Inventory in Physics (MAIP) (Geisinger, 2016). This is because, meta-cognitive awareness is a construct that does not lend itself to experimental manipulations.

The initial consideration involves sample size. The initial considerations according to Andy (2006) involves Kaiser-Meyer-Olkin Measure of sampling adequacy (KMO) and Bartlett's Test of Sphericity to check for sampling adequacy, assumption of sphericity respectively and communality which is the proportion of common variance present in a variable. The factor extraction is either based on Kaiser recommendation of retaining all factors with eigenvalues greater than 1 or Jollife suggestion of retaining all factors with eigenvalues more than 0.7 (Andy, 2006). The use of Scree plots is important because factor rotation should not be based on these criterions alone. It is pertinent to note that, the minimum number of factors that will best explain the data set or structure of the instrument as well as the factor loading of each item on each of the factors will emerge after rotation.

Factor loading are the relative contributions that a variable makes to a factor. Based on a predetermined minimum loading, the researcher selects only those items that are highly loaded on any factor. An item that loads highly on one factor is said to be pure or factorially simple. On the other hand, if an item loads highly on two or more factors, it is said to be factorially complex. The quality of the items of the instrument is also ascertained in terms of its internal consistency which is the reliability index.

Reliability of an instrument is the degree of consistency with which a measuring instrument measured what it is supposed to measure (Nworgu, 2015). For an instrument to be reliable, it has to show consistency between independent measurements of the same phenomena over times. Thus, it is the stability, dependability and predictability of a measuring instrument in producing consistent set of results in subsequent measures (Emaikwu, 2011; Nworgu, 2015). In this study, the reliability index of Meta-cognitive Awareness Inventory in Physics (MAIP) for students is established using Cronbach's Alpha. The estimate of internal consistency provides a measure of how homogenous or otherwise the items are. As a result, the present study took the position that, research instrument is best served by improvement in its reliability and usability.

The usability of an instrument refers to the extent to which the majority of the people meant to use the instrument can easily use it given the realities and practical conditions around (Emaikwu, 2011). In other words, usability of a test refers to the degree to which a test can be successfully used by the classroom teachers and administrators without undue expenditure of time, money and energy and the extent to which the examinees can understand the items and finish the test without experiencing fatigue, stress or boredom. Therefore, this study found the extent to which the secondary students can easily use Meta-cognitive Awareness Inventory in Physics (MAIP) to determine their level of meta-cognitive awareness in urban and rural school settings (location base).

School location is the urban and rural school settings of schools and this classification may have influence on teaching and learning of physics as well as the level of students' meta-cognitive awareness. According to Onoyase (2015) school location may be classified into urban, semi-urban, and rural. These classifications sometimes go a long way to influence Governments distribution of social amenities like electricity, water, hospital and educational institutions. Urban area according to Weeks (2010) is a place-based characteristic that describes the degree to which the lives of a spatial concentration of people are organized around non-agricultural activities. The rural communities on the other hand are mainly inhabited by peasant farmers. Hence, the degree to which Meta-cognitive Awareness Inventory in Physics (MAIP) can be successfully used in urban and rural areas to determine their level of meta-cognitive awareness without undue expenditure of time, money and energy deserves research attentions.

One of the basic problems of the study in the field of meta-cognition is the development and use of valid and reliable instrument for determining the level of students' meta-cognitive awareness. Literature is replete with evidence which suggests that, students irrespective of their location are unable to solve non-routine Physics problems due to low meta-cognitive awareness. Students that are aware of their thinking may be more strategic to perform better than those who are unaware. But how can students use meta-cognitive strategies in Physics while learning if they are not aware of their meta-cognition? The awareness of meta-cognition plays an important role in education because, it helps learners to develop a plan on how to monitor and evaluate their learning processes. With reference to the domain-specific property of meta-cognitive awareness, the development of Meta-cognitive Awareness Inventory (MAI) specific to physics is imperative.

Research Questions

The following research questions were raised to guide the study:

1. What is the construct validity of the items of the Meta-cognitive Awareness Inventory in Physics (MAIP) for secondary schools in Benue state in terms of their factor loadings?
2. What is the internal consistency reliability index of Meta-cognitive Awareness Inventory in Physics (MAIP) for secondary schools in Benue state, Nigeria?

3. What is the mean meta-cognitive awareness rating of students in urban and rural areas using Meta-cognitive Awareness Inventory in Physics (MAIP) for secondary schools in Benue state, Nigeria?

Hypothesis

There is no significant difference in the mean meta-cognitive awareness ratings of students in urban and rural areas using Meta-cognitive Awareness Inventory in Physics (MAIP) for secondary schools in Benue state, Nigeria.

Method

The study adopted instrumentation research design. The population for the study comprised all the 15030 Senior Secondary Two (SSII) science students in the 2319 Secondary Schools. The sample comprised 1382 SSII students that offered Physics as a school subject for 2020/2021 Academic Session. The instrument for data collection was Meta-cognitive Awareness Inventory in Physics (MAIP). The Meta-cognitive Awareness Inventory in Physics (MAIP) was face validated by five experts and the observations of these experts were used for the review of the items of the instrument. Construct validation was carried out on the Meta-cognitive Awareness Inventory in Physics (MAIP) for secondary schools to establish its construct validity using factor analysis. This is based on the extraction method of principal component analysis and rotation method of Varimax with Kaiser Normalization. The item selection was done using the rotated component matrix. The items with factor loading of 0.40 and above on any of the factors were identified and selected to form part of the instrument. Coefficient of internal consistency was obtained through Cronbach's Alpha and found to be 0.78. Research question 1 was answered using factor analysis. Research question 2 was answered using coefficient of internal consistency obtained through Cronbach's Alpha. Research question 3 was answered using mean and standard deviations. The null hypothesis was tested using independent t-test at 0.05 level of significance. The choice of independent t-test as a statistical technique is because of the fact that, each of the null hypotheses dealt with two groups that is self-determining.

Results

Table 1.

Construct Validity of the Items of Meta-cognitive Awareness Inventory in Physics (MAIP) in Terms of their Factor Loadings

Factor 1				Factor 2		Factor 3		Factor 4		Factor 5	
Item	Loadings	Item	Loadings	Item	Loadings	Item	Loadings	Item	Loadings	Item	Loadings
9	0.56	33	0.62	1	0.62	2	0.60	3	0.56	8	0.43
10	0.65	34	0.64	4	0.50	6	0.48	7	0.47	9	0.41
11	0.63	35	0.65	5	0.62	44	0.47	31	0.49	16	0.49

12	0.55	36	0.57	6	0.42	51	0.65	38	0.50	49	0.41
13	0.64	37	0.56	8	0.62	54	0.44	52	0.53	56	0.49
14	0.64	38	0.43	11	0.42	55	0.49	59	0.46	65	0.42
15	0.68	39	0.64	29	0.43	58	0.58	63	0.47	70	0.50
16	0.56	40	0.59	32	0.58	61	0.45	66	0.69		
17	0.58	41	0.61	33	0.45	62	0.46	73	0.67		
18	0.63	42	0.70	39	0.41	63	0.44	74	0.43		
19	0.66	43	0.67	40	0.42	65	0.52				
20	0.67	44	0.67	46	0.49	68	0.45				
21	0.70	45	0.65	47	0.41	71	0.50				
22	0.66	46	0.57	53	0.73	72	0.48				
23	0.57	47	0.50	54	0.44	75	0.54				
24	0.71	48	0.55	57	0.64						
25	0.72	49	0.67	60	0.68						
26	0.69	50	0.65	61	0.45						
27	0.45	55	0.41	62	0.42						
28	0.69			64	0.65						
29	0.60			67	0.69						
30	0.50			68	0.47						
31	0.64			75	0.45						
32	0.46			76	0.40						

Table 1 reveals that items 1, 2, 3, 4, 5, 7, 10, 12, 13, 14, 15, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 30, 34, 35, 36, 37, 41, 42, 43, 45, 48, 50, 51, 52, 53, 55, 56, 57, 58, 59, 60, 64, 66, 67, 70, 71, 72, 73, 74 and 76 loaded more than 0.4 on only a factor. The loading of the items on only one factor shows that the items are factorially simple or pure items. The table further reveals that items 6, 8, 9, 11, 16, 29, 31, 32, 33, 38, 39, 40, 44, 46, 47, 49, 54, 61, 62, 63, 65, 68, and 75 loaded more than 0.4 on two factors. The loading of these items on more than one factor shows that these items are factorially complex. Therefore, the construct validity of the items of the Meta-cognitive Awareness Inventory in Physics (MAIP) for secondary school students in Benue State in terms of their factor loadings is that, the MAIP has 52 factorially simple or pure items and 23 factorially complex items in terms of their factor loadings.

Table 2.
Estimate of coefficient of Internal Consistency of Components of Meta-cognitive Awareness Inventory in Physics (MAIP)

Cluster	Components of Meta-cognition	No of Items	Reliability Index
1	Declarative	15	0.92
2	Procedural	8	0.89
3	Conditional	6	0.87
4	Monitoring	8	0.91
5	Evaluation	11	0.93
6	Debugging	8	0.87
7	Planning	6	0.82

8	Information Management	13	0.91
Total	**Overall**	**75**	**0.98**

Analysis of data in Table 2 shows that declarative knowledge with 15 items has coefficient of internal consistency of 0.92 while procedural knowledge with eight items has coefficient of internal consistency of 0.89, and conditional knowledge with six items has coefficient of internal consistency of 0.87. The table further reveals that, monitoring with eight items has coefficient of internal consistency of 0.91 while evaluation with 11 items has coefficient of internal consistency of 0.93 but debugging with eight items has coefficient of internal consistency of 0.87 and planning with six items has coefficient of internal consistency of 0.82, then information management with 13 items has coefficient of internal consistency of 0.91. Based on excellent reliability (0.90 and above), high reliability (0.70-0.90), moderate reliability (0.50-0.70) and low reliability (0.50 and below). The coefficients of internal consistency of the sub-scales show that, declarative knowledge, monitoring, evaluation and information management have excellent internal consistency while procedural knowledge, conditional knowledge, debugging and planning have high internal consistency. The coefficient of internal consistency of Meta-cognitive Awareness Inventory in Physics (MAIP) for secondary school students in Benue State is 0.98. This coefficient shows that the MAIP has excellent internal consistency hence reliable.

Table 3.

Mean, standard deviation and t-test of Meta-cognitive Awareness ratings of Students in Urban and Rural Areas using Meta-cognitive Awareness Inventory in Physics (MAIP)

School Location	N	Mean	Standard Deviation	t	df	Sig	Remark
Urban	635	2.84	0.53	31.851	1380	0.000	sig
Rural	747	1.97	0.49				

N = Number of respondents, t = Critical value of t-test, df = Degree of freedom

Table 3 shows that, the mean meta-cognitive awareness of students in urban senior secondary schools is 2.84 with a standard deviation of 0.53 while the mean meta-cognitive awareness of students in rural area is 1.97 with the standard deviation of 0.49. The difference in the mean meta-cognitive awareness rating of students in urban and rural areas using MAIP is 0.87 in favour of students in urban area.

The table further shows that, the probability associated with the critical value of t (31.851) at df = 1380 is 0.05, since the probability value of 0.000 is less than 0.05 level of significance, the test statistic is significant and therefore, the null hypothesis is rejected. Thus, there is significant difference in the mean meta-cognitive awareness ratings of students in urban and rural areas using Meta-cognitive Awareness Inventory in Physics (MAIP) for secondary schools in Benue State, Nigeria. Hence, school location is a factor in meta-cognitive awareness rating of students using MAIP.

Discussion

The study found that, the Meta-cognitive Awareness Inventory in Physics (MAIP) has excellent psychometric property of construct validity. A higher percentage of the items of MAIP are factorially simple or pure. Few items were cross loaded on more than one interpretable factor and were considered factorially complex. Explicitly, the high number of factorially simple or pure items found in this study may be due to the high mean meta-cognitive awareness ratings found for students in urban areas and private senior secondary schools across the area of study. Furthermore, the complex items of Meta-cognitive Awareness Inventory in Physics (MAIP) in terms of their factor loadings may be the result of the interaction between the shifting conception of meta-cognition and external effects such as the students' culture, background and learning styles. The difference in conception could be a measurement artifact arising from biases that are typically found in self-reported inventory such as the MAIP.

The finding agrees with that of Fung & Leung (2017) that, factor analysis with Oblimin rotation yielded four factors which were classified as prediction, planning, monitoring and evaluation according to the content of the items. The finding also agrees with that of Harrison & Vallin (2018) that, the 52 items function better as two theoretical dimensions, knowledge and regulation, than as a single dimension. Even though the two dimensions correlated strongly, the factor structure better explained the empirical data than did that of the unidimensional model. It was also found that, this theoretical structure fit better than that based on Schraw and Dennison's exploratory factor analysis, which places into question scoring procedures based on that structure. The finding concure with that of Sirajuddin et al. (2018) that, the result of empirical validation is 45 items are valid in topics of Newton's law, gravitational force, work and energy, momentum and impulse, and harmonic motion and I-KPS is valid instrument both theoretically and empirically. The finding also agrees with that of Aurah et al. (2018) that, the assessment instrument is valid in the content validation and the empirical validation and able to measure Physics problem solving skills. The finding agrees with that of Panaoura & Philippou (2019) that, first order factor contained items for the knowledge of cognition and a different first order factor contained items for the regulation of cognition. The finding is consistent with that of Haeruddin et al. (2020) that, the Physics Meta-cognition Inventory (PMI) has good valid psychometric properties. Therefore, PMI can be used to measure the level of meta-cognition of students when solving physics problems. However, the finding disagrees with that of Teo & Lee (2012) that, the eight-factor hypothesized model that underlies the responses to the 52 items in the MAI did not fit adequately.

The finding in respect of the coefficient of internal consistency of Meta-cognitive Awareness Inventory in Physics (MAIP) for secondary school students in Benue State revealed that each cluster of the MAIP has high and excellent coefficient of internal consistency. The coefficient of internal consistency of MAIP was 0.98. This coefficient shows that the MAIP has excellent internal consistency that is considered reliable. The high coefficient of internal consistency found for MAIP for secondary school students in Benue State may be based on the fact that, the instrument measures the acquisition of domain-specific awareness within specific subject matter of instruction. The high coefficient of internal consistency found for the clusters of MAIP and the coefficient of internal consistency of the instrument shows the consistency of the ratings for different items for the same construct within the measured construct. The reliability results determine the extent to which individual difference in the ratings on the inventory are attributed to true differences in the constructs or the characteristics of students offering Physics as a school subject in the study area. That is whether the observed individual differences are simply a result of chance or biased errors. The finding revealed that, the Meta-cognitive Awareness Inventory in Physics (MAIP) has displayed high and excellent reliability which indicates minimum error of variance.

The findings also agree with that of Heli et al. (2017) that, the internal consistency of all the factors was found good and, moreover, the Alpha of the entire questionnaire was 0.90. The finding is consistent with that of Rahmawati et al. (2018) that, *the* value of the reliability coefficient (α) of 0.87 indicated that the instrument of Conception Test on Electrical and Magnetism topics was valid and sufficient to measure students' conception on electrical and magnetism topic. The finding is consistent with that of Sirajuddin et al. (2018) that, the reliability coefficient of Science Process Skills Instrument (I-KPS) is 0.935 and that the I-KPS is reliable instrument both theoretically and empirically. The finding agrees with that of Unlu & Dokme (2019) that, the measurement reliability of the sub-scale ranges from 0.87 to 0.72 and that the Cronbach's Alpha reliability coefficient for the whole scale was calculated as 0.92. The finding agrees with that of Panaoura & Philippou (2019) that, the inventory demonstrated an overall high reliability of Cronbachs' Alpha 0.83. The finding is consistent with that of Azza & Mundilarto (2020) *that, the reliability of the items of* Physics Cognitive Learning Achievement was 0.89 for the ability ranging from -2 to 2 with standard error measurement 0.23, which means it was in a very high category. The finding is consistent with that of Ike et al. (2020) that, the result of this research obtained a reliable Concept Mastery Test that is enriched with all four types of representations.

Findings in respect of mean meta-cognitive awareness ratings of students in urban and rural areas using Meta-cognitive Awareness Inventory in Physics (MAIP) revealed that school location influenced mean meta-cognitive awareness ratings of students. It was found that, there was significant difference in the mean meta-cognitive awareness in Physics of students in rural and urban areas in favour of students in urban area using MAIP. This implies that, students in urban and rural senior secondary schools showed discrepancy in their mean meta-cognitive awareness in Physics based on MAIP ratings.

The significant difference found in the mean meta-cognitive awareness of students in urban and rural senior secondary schools based on Meta-cognitive Awareness Inventory in Physics (MAIP) ratings in favour of students in urban area may be due to the verity that, the urban settlements possess facilities like water, electricity, radio, television, cars among others which make life comfortable for the inhabitants. The presence of these facilities may attract more qualified teachers to the locations and because of the comfort, they remain there and put in the best in their jobs thereby, enhancing mean meta-cognitive awareness of students. The infrastructural facilities present in urban area tend to pull the elite of the society that have the economic power and so are able to provide the learning facilities needed by their children. They are also able to employ private teachers to teach their children at home after school. These may probably enhance their meta-cognitive awareness. The finding agrees with that of Rekha (2013) that, meta-cognitive level of urban students differ significantly from their rural counterparts. However, the finding disagrees with that of Sabitu et al. (2012); Jaleel & Premachandran (2016) that, secondary school students are identically distributed among each group in their meta-cognitive awareness and that, there is no significant difference in the meta-cognitive awareness of secondary school students based on their location.

Conclusion

The Meta-cognitive Awareness Inventory in Physics (MAIP) for secondary school students in Benue State has excellent psychometric properties of construct validity, reliability and usability. The Meta-cognitive Awareness Inventory in Physics (MAIP) is effective in determining the level of meta-cognitive awareness in Physics of students in urban and rural senior secondary schools in Benue State, Nigeria.

Recommendations

The following recommendations were made in the light of the findings of this study:

1. Students should use the Meta-cognitive Awareness Inventory in Physics (MAIP) to determine their level of meta-cognitive awareness in both urban and rural schools. This may enable them to gain awareness and control over themselves as learners for effective learning of Physics in secondary schools irrespective of their locations.
2. Physics teachers should use the Meta-cognitive Awareness Inventory in Physics (MAIP) to determine the level of their students' meta-cognitive awareness in both urban and rural schools. This may help them bridge the gap between their students' level of meta-cognitive awareness.

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Conflict of interests

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