MULTIPLE CAUSAL REASONING ABOUT BIOLOGICALLY ADAPTIVE CHANGES IN LIVING ENTITIES: INFLUENCE OF YEARS OF BIOLOGY EDUCATION

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Abstract

Causal reasoning is very important in concept formation and any good science curriculum must seek to develop scientific mechanisms in the students. In this study, Senior Secondary (N=360) students were engaged in an investigation that sought to determine if differences exist in patterns of causal reasoning across three year levels, which is indicative of the influence of additional years of biological education. A student subsample (N=36) was engaged in in-depth interviews. Results from multivariate chi square analysis showed no significant differences between the different year levels; however, the older students were more likely to employ target-dependent thinking and consistently use a preferred causal explanation. Secondly, results indicate that causal reasoning is nuanced, sometimes reflecting the students' level of understanding of the causal relations within an entity. In other words, the result supports other research findings that uphold the coexistence of multiple explanatory frameworks and the tenacity of already acquired causal mechanisms even in the face of additional years of biology instruction. The paper concludes by calling on the science education community to make causal reasoning central in science instruction at the secondary school level.

Keywords: causal reasoning; biology education; humans, other animals, plants and senior secondary school students.

That children develop causal reasoning about biological entities before they enter school is a well-documented fact (Coley, Arenson, Xu & Tanner, 2017; Inagaki & Hatano, 2006, 2008; Hatano& Inagaki, 1994; Hatano, Siegler, Richards, Inagaki, Stavy, & Wax, 1993, and Legare, Gelman, Wellman &Kushnir, 2008). These naïve reasoning patterns are explanatory frameworks developed about the biological world by an individual. These are informal and intuitive and quite often do not conform to expert views. They are also not in consonance with popular views or cultural leanings as culture begins to influence children's reasoning from about the age of 4 years (Carey, 1985, 1995) and children begin to acquire culturally specific explanatory frameworks as they grow older (Busch, Watson-Jones &Legare, 2017; Legare & Gelman, 2008; Panagiotaki, Hopkins, Nobes, Ward & Griffiths, 2018; Watson-Jones, Busch &Legare, 2015)

Causal reasoning, that is, the process of thinking about cause and effect, arise from the human mind's tendency to provide causal explanations to the questions of 'why', 'how' and 'what'. Development of causal reasoning is particularly important in science learning as scientific inventions such as hypotheses, theories and laws specify causal relations among entities, events and processes (Gopnik, Sobel, Schulz &Glymour, 2001). Causal knowledge grants the ability to develop abstractions about the world which enables the individual to act on it (Walker &Gopnik, 2013). Causal learning is, therefore, very important in science learning as a good understanding of causal relations can lead to theory formation and change.

Researchers have tried to characterize causal reasoningand to investigate how these might change as a result of maturation, environment and experience (Coley & Tanner, 2012). One such characterization, Tamir and Zohar (1991), adopted a seven-category scheme. This is comprised of teleological, anthropomorphic, mechanistic proximate, mechanistic ultimate, predetermined, blended and 'I don't know" causal categories. Other characterizations collapse Tamir and Zohar's categories into a fewer number, thus, giving rise to fuzzy boundaries (e.g. Inagaki &Hatano, 2008; Author, 2000). For the purposes of this work, we have adopted Tamir and Zohar's categorization scheme.

Tamir and Zohar (1991) defined anthropomorphic (A) reasoning as a reasoning category in which explanation is based on human attributes as the causal agent for changes seen in non-human organisms; it also includes an explanation of humans and nonhuman organisms as being able to cause the desired biological change by themselves. Teleological (T) reasoning is any explanation based on need as being the agent of biological change, it assumes that a feature exists for a purpose (Kallery&Psillos, 2004; Keleman, 1999). Mechanistic proximate (MP) explanation is the reasoning category in which a specific physiological/biological or external agent is identified. Typically, such an explanation describes just the individual being observed and does not consider the entire group or population of organisms. Mechanistic ultimate (MU) explanation is the reasoning category in which a long-term (generally, genetically-based) agent is identified. This is the evolutionary reasoning category because such an explanation describes the evolution of the entire population of organisms, and not just an individual. Predetermined (P) reasoning category is one in which the causal agent of the biological phenomenon is identified as a supernatural being, such as God, a god, a spirit, or an unknown supernatural agent. Blended (B) category is the reasoning category in which the respondent gives an explanation that fulfills the requirements of more than one of the above reasoning categories within the span of a single response. The last, "don't know" (DK) category, is where the respondent indicates he or she does not know the cause agent.

Causal reasoning and biology education

Whether instruction and additional biology education can achieve adequate revision of naïve biological explanations has been the focus of much debate and research in biology education (Coley et al, 2017; Coley & Tanner, 2012, 2015; Goldberg & Thompson-Schill, 2009; Nehm& Reilly, 2007). Research has shown that before school age, children have developed naïve ways of reasoning about biological entities and causal relationships (Au &Romo, 1999; Coley & Tanner, 2012, 2015).These studies also demonstrated a counterintuitive trend—that additional years of biology education/experience or accumulation of biological/mechanistic knowledge at best increases the understanding but not the use of mechanistic reasoning. For example, Coley and Tanner (2015) working with biology majors and non-majors found no differences between the two groups of students in their use of biology explanations in reasoning about biology-based problems, although, differences were noticed in the number of misconceptions held by the students. The study clearly demonstrated that there are "important linkages between intuitive ways of thinking and misconceptions in discipline-based reasoning, and raise questions about the origins, persistence, and generality of relations between intuitive reasoning and biological misconceptions" (Coley & Tanner, 2015, p. 1).

Au and Romo (1999) interviewed children from low- and high- income socio economic backgrounds and found that there were no differences in the children's explanation of biological phenomena. They concluded that children always refer to their naïve biology in the explanation of biological phenomena. They claim that children and, in fact, adults do not have adequate mechanistic explanations of biological phenomena without any biological knowledge input. It would seem that expecting people to construct mechanistic explanations from their everyday experiences would be expecting too much. However, they argue that the tendency to offer proximate mechanistic (mechanical causality in Au &Romo, 1999) explanations is robust in middle childhood through early adolescence. For children in secondary school therefore, it would be expected that as the years of biological education increases, the level of use of ultimate mechanisms—what Au and Romo (1999) referred to as biological explanations—would increase.The question that we address in the present study is whether additional biology education is associated with students causal reasoningabout humans, other animals and plants. If this is the case, we would expect a difference in the causal explanation of choice of students at the different Year Levels; the students with the highest number of years of biology education would be expected to use more biologically accepted causal explanations than students with lesser number(s) of years of biology education.

Research Questions

Do secondary school students differ in their causal reasoning about humans, animals and plants as a function of biological knowledge? If so, there should be a difference in the pattern of causal reasoning between Senior Secondary Year 1 (SSI), Senior Secondary Year 2 (SSII) and Senior Secondary Year 3 (SSIII) students—with the use of mechanistic explanations increasing with increase in biological knowledge, that is, increase in year level (Year Level). However, if use of mechanistic causal reasoning does not require a threshold of biological knowledge, then there should be no difference between the year levels in the pattern of causal reasoning adopted to explain biologically adaptive changes in humans, plants and other animals. In other words, the different causal categories will be recruited more or less equally across the year levels. These hypotheses were put to test in the present study, that is, this study tested whether there are differences in patterns of causal reasoning among SSI, SSII and SSIII students which is indicative of the influence of varied years of biological education exposure.

Specifically, the study addressed the following questions:

1. Are the proportions of students recruiting the different causal explanations in making causal attributions regarding biologically adaptive changes in humans, other animals and plants significantly associated with the prompt type?
2. Are the proportions of students recruiting the different causal explanations in making causal attributions regarding biologically adaptive changes in humans, other animals and plants significantly associated with the Year Level?
3. Is there an association between Year Level (SSI, SSII and SSIII) and prompt type (humans, other animals and plants) in students' use of the different causal explanations?

Research Instrument

The instrument used for this research was the questionnaire developed by the authors. The principle of the Ordered Multiple-Choice items was adopted; in which the "distractors" reflect viable alternative conceptions. Eighteen students from two schools, other than the ones that participated in this study, were asked to give free responses to questions related to the six prompts used in this study (Figure 1) and their responses were analyzed for categories. The prompt types in this study are human (an albino and a developing human foetus showing umbilical cord); other animals (*Acrida conica*, specie of grasshopper that exhibits *seasonal variation in colour*—green in rainy season, and brown in dry season; and a scorpion with *prominent pedipalps*and *the stinger)*; and plants (cactus plant with s*pines* and fluted pumpkin shoot system with *tendrils*).

Given the cultural context of these students, it is expected that the prompts will prime ideas related to all the categories of reasoning pattern adopted in this study.

The categories that emerged from the free responses were then used as the Ordered Multiple-Choice options to the three questions asked regarding each prompt. Since these represented the reasoned viewpoints of students, they were not scored, rather, nominal values were assigned to them for the purposes of analysis (see Appendix 1for sample questions).

The questionnaire was face validated by three experts, from the fields of Biology Education, Measurement and Evaluation, and Educational Psychology to check for language accuracy and complexity and if indeed a valid mechanistic viewpoint was accommodated. The draft questionnaire was given to three researchers working in the area of reasoning patterns. They were required to code each alternative to the three questions for each prompt using Tamir and Zohar (1991) categorization scheme. An inter-rater reliability test was conducted using the Kendall's *W* to determine the extent to which the researchers agree in their assignment of alternatives to a category. The coefficient of concordance was 0.944 indicating that the questionnaire could be used with a high degree of accuracy with this group of students. The questionnaire was then administered to 20 students from a school in the same area that was not part of the sample. This was to check if each alternative represented a viable viewpoint. All alternatives were selected by some students indicating that they indeed represented viable viewpoints. Students were expected to select from the pool of seven reasoning categories the response that best represented their causal reasoningabout a biologically adaptive phenomenon under consideration.

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Data Coding

Data from the questionnaire were assigned nominal values 1-7 in no particular order: Teleology (1), Anthropomorphic (2), Mechanistic Ultimate (3), Mechanistic Proximate (4), Predetermined (5), I don't Know (6) and Blended (7). A student is coded as blended when they tick more than one category of causal reasoning for a questionnaire item. In analysis, the reasoning categories appeared as discrete data and each response was treated as a single observation.

Data Analysis

An initial descriptive analysis was done using percentages. This was followed by a multivariate (3 x 3 x 7) chi square test. This involved the control variable (3 Year Levels), the explanatory variable (3 prompt types—human, other animal and plant) and the response variable (7 reasoning categories). Post hoc tests were then carried out to determine for which specific category(ies) of causal reasoning there were significant differences between each pair of Year Level (e.g. SSI vs SSII) or prompt type (e.g. human vs plant). The probability level was set at $p < 0.05$ which was then corrected using the sequential Bonferroni test for the different partial tables. For analysis with 6 degrees of freedom, probability was set at $p<0.004$ and for those with 12 degrees of freedom, probability was set at $p<0.002$. This is in order to counteract the problem of multiple statistical/pairwise comparisons. To determine whether there were significant associations among reasoning patterns, prompt type and Year Level, adjusted p-values were calculated for each pairwise comparison.

The interview data was analysed descriptively. Coding was not necessary as the responses of the students were used to explore the consistency of the students in their causal attributions and what types of explanations were blended together? It explored how, why, and the implications of such blending? It also revealed if each specific blending correlated at all with native epistemologies in the way the literature suggests they might be in the Igbo culture.

Results

Association of students' causal reasoning with the prompt types

Our data (Table 1) shows the prevalence of the mechanistic ultimate reasoning category among our student sample (23.8%). This was followed by the recruitment of the mechanistic proximate explanations (23.5%), teleology (17.2%), predetermined explanations (13.1%), anthropomorphic explanations (10%), blended explanations (9.5%) and don't know category (2.9%) in that order. The nuancing of these proportions by the prompt type is readily observable (Table 1) as the percentages show for our three prompt types. Whereas the mechanistic proximate was the most preferred causal explanation for the plant (28.9%) and other animal (29.2%) prompts, mechanistic ultimate was the preferred causal explanation for the human prompt type (43%). The proportions of students recruiting teleological explanations for other animals (20.1%) and plants (19.1%) ranked next to mechanistic proximate explanations. Whereas for the human prompt type the proportion of students that recruited teleology (12.3%) ranked next to mechanistic proximate (12.5%) and predetermined explanations (13.4%).

Table 1 Percentage of students by Prompt-Type recruiting the different causal explanations

	Reasoning Pattern						
	Teleological	**Anthropomorphic**	**Mechanistic Ultimate**	**Mechanistic Proximate**	**Predetermined**	**Don't know**	**Blended**
Human	12.3%	4.6%	43.0%	12.5%	13.4%	5.0%	9.2%
Other							

Animal	20.1%	10.0%	14.5%	29.2%	13.8%	1.5%	11.0%
Plants	19.1%	15.3%	14.0%	28.9%	12.3%	2.2%	8.2%
Total	17.2%	10.0%	23.8%	23.5%	13.1%	2.9%	9.5%

Patterns for other animals and plants differed statistically significantly only in the use of anthropomorphic explanations (*χ^2 = 28.09, df= 6, n = 4320, p<0.00009).* The proportion of students using the predetermined explanation was similar across the three prompt types. Patterns differed between the human prompt type on one hand and the other animal and plant prompt types on the other hand on all causal explanations except for the predetermined and blended categories where no statistically significant differences were found (teleological *Human vs Other Animalsχ^2 = 49, df= 6, n = 4320, p<0.0000, Human vs Plantsχ^2 = 38.44,df= 6, n = 4320, p<0.0000*; anthropomorphic *Human vs Other Animalsχ^2 = 44.89, df= 6, n = 4320, p<0.0000, Human vs Plantsχ^2 = 136.89, df= 6, n = 4320, p<0.0000*; mechanistic ultimate *Human vs Other Animals χ^2 = 428.49, df= 6, n = 4320, p<0.0000, Human vs Plantsχ^2 = 445.21, df= 6, n = 4320, p<0.0000* mechanistic proximate *Human vs Other Animalsχ^2 = 179.46, df= 6, n = 4320, p<0.0000, Human vs Plantsχ^2= 176.89,df= 6, n = 4320, p<0.0000; don't know Human vs Other Animalsχ^2 = 40.96, df= 6, n = 4320, p<0.0000; Human vs Plantsχ^2 = 23.04, df= 6, n = 4320, p<0.00008*).

Association of Years of biology Education and Students' Causal Reasoning

Data (Table 2) determining the association between Year Level and the students' reasoning pattern was statistically significant (*χ2=109.91, df = 12, n = 6480, p <0 .000*). This was an indication that reasoning pattern differed statistically significantly between the three year levels. Adjusting the probability for all pairwise comparisons, it was found that there were no statistically significant differences between the three year levels with respect to all reasoning categories except the blended category. For the blended category, a statistically significant (*χ2 = 37.21, df = 12, n = 6480, p < 0.0001*) higher number of SSI students used more than one causal category in a span of a single response for biologically adaptive changes in humans, other animals and plants whereas a statistically significant (*χ2 = 62.41, df = 12, n = 6480, p < 0.000*)lower number of SSIII students did the same. The prediction of independence was true for SSII students.

Table 2 Percentage of students by Year-Level recruiting the different causal explanations

	Reasoning Pattern (%)						
YEAR LEVEL	**TELEOLOGICAL**	**ANTHROPOMORPHIC**	**MECHANISTIC ULTIMATE**	**MECHANISTIC PROXIMATE**	**PREDETERMINED**	**DON'T KNOW**	**BLENDED**
SSI	17.8%	11.3%	21.2%	21.2%	13.8%	2.0%	12.7%
SSII	15.5%	9.1%	23.3%	25.8%	13.0%	2.9%	10.4%
SSIII	18.2%	9.5%	26.7%	23.6%	12.7%	3.8%	5.5%
Total	17.2%	10.0%	23.8%	23.5%	13.1%	2.9%	9.5%

$\chi 2=109.91,\ df = 12,\ n = 6480,\ p <0 .000$

`To further check for which pair of year levels there were significant differences and the reasoning categories where the differences occurred, three additional post hoc tests were done. The result suggested no statistically significant differences between SSI and SSII students in all reasoning categories. There were, however, statistically significant differences between SSI and SSIII ($\chi 2 = 67.24,\ df = 6,\ n = 4320,\ p <0.000$) and between SSII and SSIII ($\chi 2 = 36.00,\ df = 6,\ n = 4320,\ p = <0.000$) for the blended category only. This is an indication that increase in years of biology education is not associated with the causal explanations employed by students in causal attributions;rather, it aids students in being consistent in their choice of causal explanations as the number of SSIII students using more than one category in the span of a single response was statistically significantly lower than would be expected for this group of students. The result suggests that more biological schooling is associated with greater consistency in causal reasoning.The implications of this was explored using the interview protocol.

Association of Prompt Type, Year Level and Students' Causal Reasoning

With this interesting pattern noted, the data was probed to find out if this pattern was true for all three prompt types (human, other animals and plants). Again, the multivariate analysis confirmed a statistically significant association between Year Level and reasoning pattern for all three prompt types (*Human Prompt*$\chi 2 = 29.14; df = 12; n = 6480, p<0.004$; *Other Animal Prompt* $\chi 2 =63.46; df = 12; n = 6480, p<0.000$; *Plant Prompt* $\chi 2 = 57.84; df = 12; n = 6480, p<0.000$). However, adjusting the p for all pairwise combinations it was confirmed that the prediction of independence was true for associations between the three Year Levels and all causal reasoning categories relating to the three prompt types except for the other animal category where a statistically significant ($\chi 2 = 32.49, df = 12, n = 6480, p< 0.001$) higher number of SSI students used more than one category in the span of a single response (blended category) and a statistically significant ($\chi 2 = 31.36, df = 12, n = 6480, p< 0.002$) lower number of SSIII students did the same.

Discussion

Association of Prompt Type and Students' Causal Reasoning

The data showed that patterns differed greatly between humans on the one hand and other animals and plants on the other hand. A very high proportion of the students were more likely to recruit mechanistic ultimate explanations for humans, and less likely to do so for other animals and plants whereas high proportions were more likely to endorse mechanistic proximate explanations for other animal and plant prompts. This tendency supports the conclusion that the students resorted to guessing when they were not very knowledgeable about relations within an entity. Evidence abound from empirical studies (Leddon et al. 2012; Lindemann-Matthies, 2005; Tarlowski, 2006) confirming that individuals from non-western cultures do not fully understand the place of other animals in the biological world. Authors 2 demonstrated that students from the Igbo culture associate other animals more closely with plants than with humans, leading to a confusion of causal relations within that category. As one of the students said of the grasshopper, "...it is a plant animal…". This might be because the human is placed in a totally different category by the Igbo thought system. Man is the only entity with a soul and a spiritual component, other animals and plants share a common character of being entirely physical, without souls. The result of this study is suggestive of the role this thought system may play in the causal reasoning of the student sample.

Association of Years of Biology Education and Causal Reasoning

Furthermore, the contribution of years of biology education to change in causal reasoning was explored. It was hoped that studying students from the same background, who were receiving similar biological knowledge input would clearly show the impact of increased years of biology education on causal reasoning. Surprisingly, no statistically significant differences were observed across the three prompt types in the causal explanations adopted among students of different Year Levels except for the blended category. Results showed that a statistically significant higher number of SSI students made use of more than one causal category in the span of a single response, whereas the number of SSIII students that did the same was statistically lower than expected for this sample of students. On the other hand, the number of SSII students that used more than one causal explanation in the span of a single response equaled the number expected for this group of students. This is an indication that as the year level increased, the tendency to use more than one causal category in the span of a single response decreased. In other words, the older students were more likely to use target-dependent thinking just as adults in Panagiotaki et al.'s (2018) study. The results therefore, suggest that maturation may have a greater influence on biological thinking than increase in biological/mechanistic knowledge as there were no statistically significant differences between the year levels across inthe causal reasoning categories.

Another form of coexistence noticed among this sample of students is the integrated reasoning. When asked why the foetus has an umbilical cord one of the students responded that "*God designed it for the mother and the baby. Man is made in the image of God and God has designed every part of his body and this is passed from parents to children".* In this form of reasoning, evolutionary, supernatural and naturalistic causes are linked in a causal chain with the supernatural (God, gods, witches, etc.) placed as the first or distal cause (Evans, 2001, 2008; Kanu, 2014). In the current study, SSI students were more likely to use this form of reasoning (blending) than SSII students who in turn were more likely to employ it than SSIII students.

Emerging from the above is the lack of any sense of mechanisms among the student sample. The biologically adaptive change came to be because they were predetermined by God or caused by a witch. This derives from the Igbo cultural conception of causality (Kanu, 2014). God is conceived as the ontological cause, the force that causes all other things to be. The ontogical cause therefore, determines the causal pathway and effect of other causes.

Conclusion

This study has contributed to the data on the influence of increased biological knowledge on causal reasoning of students. If understanding of mechanistic causal relations helps in the development and revision of theories, and as studies show, increased biological knowledge does not lead to any meaningful revision of causal reasoning how will teachers work to achieve revision of students' causal reasoning. As biology teachers, we may need to look outside of our regular teaching protocols to culturally acquired notions of mechanisms and how these can be reconciled with the correct conceptions of the biological world. We must, therefore, give more time to understanding the nature of culturally acquired mechanisms held by students in order to determine how they interact with development of mechanistic causal reasoning. Coley and Tanner (2015, p. 1) clearly demonstrated that there are "important linkages between intuitive ways of thinking and misconceptions in discipline-based reasoning, and raise questions about the origins, persistence, and generality of relations between intuitive reasoning and biological misconceptions". This is critical in science education's emphasis on the teaching of the nature of science. Causality is central to science and more instructional attention should be given to the acquisition of accurate mechanistic reasoning, which for the generality of students is difficult to comprehend. For students from indigenous societies, much of the difficulty in the understanding of the nature of science might be traced to their culturally acquired notions of causality. Perhaps, a change in strategy and agenda with causal reasoning at the core of science teaching, identifying nature of interaction between and interference of culturally acquired notions of mechanisms and correct conceptions of scientific mechanisms would yield better results in our quest for students' understanding of science and the nature of science.

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