Fostering Pre-University Students' Argumentation Skills through Life Cycle Analysis of Plastic

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Abstract

The aim of this qualitative study was to contribute to education for sustainable development by developing and evaluate a life-cycle analysis project on the topic of plastics for secondary school students. This study evaluates the effects of doing such a project regarding the argumentation skills of the students. The central research question addressed is: what are the effects of students performing a life-cycle analysis on their argumentation skills regarding sustainability? The research method for this study was content analysis on written argumentative essays (N=10) using a coding scheme derived from Toulmin's model of argumentation. The results show that students' argumentation skills increased. The students presented more facts on an environmental and scientific level. The level of argumentation also improved, although to a lesser extent. The type of life-cycle analysis project discussed in this paper is a suitable method for promoting students' argumentation skills as well as promoting students' understanding regarding sustainability. Future research should focus on increasing the scale of these kind of projects to further evaluate the effects. Furthermore, the tools to assess argumentation skills should be refined.

Keywords

Life-Cycle Analysis, Argumentation Skills, Toulmin's Model of Argumentation, Sustainability

Introduction

The core thought of sustainable development is “a lifestyle that consistently meet with the needs of the present generation without compromising the ability of future generations to meet their own needs (UN, 1987)”. And although discussion is still present what is meant by “sustainable development”, what is common to all the definitions is the aim to raise the well-being of society with respect to ecological, economic and societal sustainability (Burmeister & Eilks, 2012). The idea of sustainable development is not only for the economy, ecology or society-at-large, it has also become an idea in the field of education (Rauch, 2004). This has resulted in the Education for Sustainable Development movement (ESD). The philosophy behind ESD is an education which focuses on both students’ ability to actively participate in society and the development of skills which allow them to actively and sustainably shape their future society (De Haan, 2010). All domains of education are expected to contribute to ESD, and in particular, chemistry.

Chemistry encompasses numerous concepts and terms that have to do with knowledge, morals, skills and the effects of actions (Juntunen & Aksela, 2010). In addition, the chemical industry lies at the heart of every industrialized society. Products based on chemical processes are available everywhere in our lives (Bradley, 2005) and chemistry and industry are aiming at a greener chemistry (Anastas & Warner, 1998) to achieve sustainable production and end-products. Chemistry teaching should pursue the goal of raising students’ ability to better understand the role of chemistry in society (Hofstein & Kesner, 2006). From an ESD point of view, this should include perspectives such as how chemistry can affect the future, positively contribute to designing sustainable communities, aid in the proper stewardship of natural resources, encourage sustainable economics, and cope with the downside of globalization (Wheeler, 2000).

The sustainability of a process can be evaluated in a number of ways, one method, which is used often is a life cycle analysis (LCA). LCA is a technical method for evaluating the environmental burden of a product, process or activity by quantifying the net-flows of different chemicals, materials and energy (Juntunen & Aksela, 2014). Through product LCA the students may practice their higher order thinking and system thinking skills (Hogan, 2002), and at the same time raise students understanding of sustainability. LCA could be an outstanding useful tool for teaching. Although the integration of sustainable chemistry in lab work has shown the potential to change students' attitudes and knowledge, the weakness of this development is that students will not develop skills for decision-making on new or alternative technologies (Burmeister, Rauch & Eilks, 2011). This weakness could be dissolved by introducing Life Cycle Analysis (LCA) in the experiments of students during chemistry classes. This particular study aims to engage students into performing a LCA themselves in the chemistry classroom such to increase their level of argumentation when deciding the most sustainable plastic.

The frequent use of the concepts argument and argumentation in this article calls for definitions. Of the numerous definitions for argument found in the literature (Means & Voss, 1996, Halpern, 1989), Toulmin (1958) defined an argument as an assertion and its accompanying justification. Toulmin's model of argumentation illustrates the structure of an argument in terms of an interconnected set of a claim; grounds that support that claim; warrants that provide a link between the grounds and the claim; backings that strengthen the grounds; qualifier that state under which conditions the claim is true and finally, rebuttals which point to the circumstances under which the claim would not hold true (Toulmin, 1958). The exact definitions of Toulmin's aspect of an argument are listed in Table 1.

Aspect of argumentation	Definition[1]
Claim	An assertion put forward publicly for general acceptance.
Grounds	The specific facts relied on to support a given claim.
Warrant	Links the grounds to the claim and gives the grounds general support.
Backing	Generalizations making explicit the body of experience relied on to establish the trustworthiness of the ways of arguing applied in any particular case.
Qualifier	Phrases that show what kind of degree of reliance is to be placed on the conclusions, given the arguments available to support them.
Rebuttal	The extraordinary or exceptional circumstances that might undermine the force of the supporting arguments.

[1]Toulmin, 1958, Liu et al, 2010

Erduran, Simon and Osborne (2004) have illustrated that Toulmin's model can be used to judge the enhanced quality of argumentation. They specified several levels of argumentation based on combination of elements in Toulmin's model and used this to analyze the argumentation in whole-class as well as small-group student discussion. Although Toulmin's model is a flexible and valuable tool to assess the quality of argumentation, it has some shortcomings (Zohar & Nemet, 2002). Lunsford (2002) mentions that gauging the soundness of argument is, in Toulmin's terms, a 'field-dependent' matter. In the field of sustainable development arguments are commonly considered in terms of socio-economic, ethical, ecological and scientific aspects (Liu, Lin & Tsai, 2010). Juntunen and Aksela (2014) have analyzed the argument quality based on these different argument categories. The combination of Toulmin's model to analyze the level of argumentation, and the adapted categories reported and used by Liu et al. provides a suitable and useful method to assess the students' argumentation skills during the life-cycle analysis.

Up to this moment, Teaching materials which uses LCA are scarce, but studies such as performed by Juntunen and Aksela (2014) have shown that secondary school students' scientific and ecological understanding with regard to the life-cycles of products were improved during their LCA project. In their project students chose a product (e.g. trousers) and performed a LCA. Furthermore, the effects of performing a LCA on the argumentation skills of students are not researched to a great extent.

The aim of this study is to make a contribution to education for sustainable development by developing a LCA project on the topic of plastics for secondary school students. This research also aims at raising students' argumentation skills regarding sustainability. The central research question addressed in this study is: *What are the effects of students performing a life-cycle analysis on their argumentation skills regarding sustainability?*

Methods

Research Approach

Because the research question is evaluative in nature and the design of educational materials is a crucial part of the research, this project falls in the category Design-Based Research (DBR) (Bakker & van Eerde, 2015). To address the evaluative character of this study, analysis of written students' work is performed and allows for an in-depth analysis of student reasoning skills.

Participants and Setting

A total of 20 students in the fifth year of their Pre-University Education (VWO in Dutch) were studied. The students who participated in this study came from honorary courses offered by the University of Utrecht. All students are learning chemistry as one of their main subject matter for final exams. The students completed the intervention in two days, the project days were one month apart from each other.

Intervention and Data Collection Tools

The project was designed as a problem-based learning environment (PBL), this is a student centered, self-directed method where the students engage in authentic research by analyzing a problem (Barrows & Tamblyn, 1980). The problem students must solve is which plastic is more sustainable by performing a LCA experiment and analysis. The students do the practical and theoretical work themselves and must find their own knowledge. And in the end, they need to reflect on the results to solve the problem and the teacher helps and guides students during the project.

To further clarify and illustrate the structure of the data collection process, all the tasks the students performed are presented in Table 2 and explained below in detail.

Table 2.
Outline of the Intervention

Day	Time taken to perform task	Activity
	120 min.	Making a preliminary assignment for day one.
1	30 min.	Discuss the preliminary assignment on sustainability.
1	30 min.	Writing an essay about the most sustainable plastic.
1	30 min.	Having a group discussion about the best plastic
1	45 min.	Discuss the preliminary assignment on plastics.
1	150 min.	Perform three plastic synthesis and collect data for the life-cycle analysis.
	120 min.	Making a preliminary assignment for day two.
2	270 min	Synthesize poly-lactic acid and further data collection.
2	60 min.	Writing an essay about the most sustainable plastic.

As a preparatory task for the LCA project, the students had to make several assignments surrounding the topic of sustainability and the topic of polymerization. In the assignments about sustainability, students were asked to select the most sustainable cup out of three options: a plastic cup made from starch, a paper cup and a cup made from polyethene. After reading selected newspaper articles about the advantages and disadvantages of the three materials the students had to select the most sustainable cup once more and substantiate their choice. In the final part of the preliminary assignment, the students had to link the twelve principles of green chemistry (Anastas & Warner, 1998) with their written reasoning in the earlier assignments. The twelve principles of green chemistry are supplied in appendix A.

At the beginning of the first day of the project, the assignments on the topic of sustainability were discussed to ensure all students were on the same level of understanding. Then the students were asked to write an argumentative essay about why their selected cup was the most sustainable. The students had to formulate two arguments in favor of their choice, one against their statement and they had to refute the counter argument they gave. They made the essay in pairs to encourage debate between the students. This essay was analyzed and served as the pretest.

The essay was used to fire up a classroom discussion which lasted for half an hour. Because the students had written their essays the students voiced their arguments in pairs. The pairs of students chose one of three groups: One that favored the plastic cups from starch, one that favored the paper cups and one that favored the polyethene cups. The discussion was led by the teacher, making sure every pair was heard. Each pair actively participated in the debate, and each group got their chance to bring their own statements.

The preparatory tasks on the topic of polymerization were discussed to ensure that all students participating in the project had the same prior knowledge on plastics.

After the preliminary assignments were discussed, as well as the students' native ideas surrounding sustainability, the central aim of the project was stated. The aim of the project was to complete a LCA for the plastics nylon-6,6, starch-based plastic, poly lactic acid and polymethyl methacrylate and use this analysis to select the must sustainable plastic. The LCA included twelve metrics which are derived from Tabone et al. (2010). The metrics included: yield, environmental factor, purity, amount of waste, atom economy, toxicity, energy consumption, biodegradability, , recyclability, lifespan of product and price of production. The students had to acquire their data for the LCA by performing several experiments. The students were presented with the lab instructions. The experiments were: the synthesis of Nylon-6,6 using sebacoyl chloride and hexamethylenediamine (this was a demonstration), the synthesis of starch-based plastic by partial hydrolysis of amylopectin, the free radical polymerization of methyl methacrylate and the polymerization of PLA with tin(II)2-ethylhexanoate as a catalyst using lactide as the monomer.

The preliminary assignment for the second day of the project consisted of an in-depth analysis of the lab work and data processing performed on day one. The students also gathered theoretical data for the completion of the life-cycle analysis.

On the second day, students started with the synthesis of poly-lactic acid. After the synthesis, the remaining data needed for the completion of the LCA was gathered through laboratory work. Once the LCA was completed, the students were asked to add their own personal weighting factor to each of the twelve metrics studied in the project and analyze the results. Based on the results the students had to arrange the four plastics from most sustainable to least sustainable.

The final assignment of the project was that the students wrote another argumentative essay on the topic of the most sustainable plastic. They had to choose one of the studied plastics. Once more, the students had to formulate two arguments in favor of their choice, one against their statement and they had to refute the last statement. The students wrote the essay in the same groups as earlier during the project. It took about an hour to write the final essay, which served as the post test.

Data analysis

The analysis of the essays was conducted by adapting Toulmin's (1958) model of argumentation in combination with adapted categories reported by Liu et al. (2010). The aspects of the model of argumentation and the included categories as well as example quotes are listed in Table 3.

Table 3.
Aspects of Argumentation, Explanations and Example Quotes Used in the Content Analysis of the Data

Aspect of Argumentation	**Explanation**	**Example quote**
Claim	An assertion, standard or thesis.	Starch-based plastics is the most sustainable plastic.
Native Grounds	Data, facts or opinions from a non-reliable or non-existent source.	Perspex is bio-degradable[2].
Grounds socio-economic	Data or facts based on costs or benefits.	Because the costs of producing poly-lactic acid is very low.
Grounds ethical	Data, facts or opinions related to values, people, aesthetics or the future.	The plastic is easily available to all people.
Grounds ecological	Data or facts based on the environment or the twelve principles of green chemistry[1]	The resources are derived from a renewable source.
Grounds scientific	Data or facts based on scientific publications or measurements.	According to the Dutch Institute for Applied Scientific Research the one time use of paper cups costs less energy compared to using mugs.
Explicit warrant	Links the grounds to the claim explicitly.	If the resources are derived from a renewable source, the plastic is sustainable.
Implicit warrant	Links the grounds to the claim implicitly.	The synthesis requires a minimal amount of energy (implicit warrant: if a process doesn't require a lot of energy it is sustainable)
Qualifier	States the conditions under which the claim holds true.	If the laboratory production of the plastic is comparable to the factory method, …
Forced rebuttal	Acknowledges exceptions that invalidate the claim. The forced rebuttal is formulated as prescribed by the assignment.	Perspex is not bio-degradable and could therefore be called not sustainable.
Rebuttal	Spontaneously acknowledges exceptions that invalidate the claim.	If the production method of poly-lactic acid is improved, it could be the most sustainable plastic.
Backing	Deepens the grounds/warrant without an explicit connection to the claim	The source of starch-based plastic is corn, which can be produced renewable.

The exact definitions of the aspects of argumentation were formulated using an iterative approach. The pre-argumentative essays and the post-argumentative essays were firstly read, then each of the sentences were coded using a combination of the coding scheme by Liu et al. (2010) and Toulmin's (1964) model of argumentation, the results were then discussed with peers. Because not all the definitions were applicable, the definitions were slightly redefined to fit this study. The essays were coded again according to the updated scheme. To check if the coding scheme was valid, a second coder coded six essays. The results and the interrelatedness were discussed, and the aspects of argumentation were, once more, refined. Then the obtained data was coded with the final coding scheme. The second coder also analyzed the data. In the end, it resulted in reliable coding with minor differences.

The main difficulty of the original coding scheme has been in the clarification of what counts as claim, grounds, warrant, qualifiers, rebuttal and backing. In the next paragraphs the difficulties and the measurements to counter this are discussed.

The organizing of the statements in the essays into Toulmin's argument aspects required careful attention to the contextualized use of language. For example, claims can serve as a new assertion to be proven or can be in service to another claim, thus acting as grounds. Erduran et al. (2004) resolved this difficulty by defining a main claim which is the main argument position. In the case of the essays, the main claim was 'plastic X is the most sustainable plastic'. Where X refers to the student's chosen plastic.

Grounds are defined as data, facts or opinions that support the main claim (Toulmin 1958). It could be interesting to see what kind of grounds the students' use when defending a statement, this is not incorporated in Toulmin's model. Liu et al. (2010) distinguished four categories of grounds: socio-economic, ethical, ecological and scientific. Socio-economic grounds relate to costs or benefits to either people or production processes. Ethical grounds relate to values or personal opinions about aesthetics, the future or morale. Ecological grounds include aspects of the twelve principles of green chemistry or effects on the environment as grounds to support the claim. The scientific category includes grounds which have a reliable scientific source or grounds based on measurements, this includes measurements made by the students themselves. A final category, native grounds, was added to the model of Liu et al. to include grounds based on flawed concepts of students or opinions of people with no reliable scientific background (*e.g.* parents, uninformed friends, pets).

A warrant connects the grounds with the claim and give the grounds general support. Because the essays included only one main claim, the warrant (either implied or stated) connects the grounds to sustainability. The warrant can be implied or stated explicitly. Identifying an implicit warrant can be difficult to identify because the students' exact meaning of a given grounds cannot be derived with certainty from the context. In cases were no logical implicit warrant could be identified nothing was coded.

Qualifiers are phrases that show what kind of degree of reliance is to be placed on the conclusions. For example: "PLA is probably the most sustainable plastic". The word "probably" indicates that the author is not fully sure that PLA is indeed the most sustainable plastic. Therefore, the word "probably" acts as a qualifier for the claim. If a student indicates that a plastic is the most sustainable out of the four researched plastics, the student shows that outside of the four researched plastics there could be an even more sustainable one. The indication therefore acts as a qualifier.

In short, the reliability of the claim is defined by a qualifier that states under which conditions the main claim holds true.

Rebuttals are the circumstances that might undermine the claim or statements that oppose the claim. In the LCA project, the students were asked to write an argumentative essay in which they had to formulate two arguments in favor of their choice and one against their statement. Asking the students to formulate a counter argument resulted in a problem during analysis. The counter argument counts as a rebuttal for it is evident that the counter argument opposed the claim. This made it hard to see whether students formulated rebuttals naturally or because of the assignment. In cases where it was evident that the rebuttal originated from the assignment, the rebuttal was coded with forced rebuttal. In cases where it was unclear whether it originated from the assignment or it was spontaneous, the rebuttal was labeled with rebuttal.

Backing establishes the reliability and relevance of the grounds or warrant. It supports the grounds without a direct connection to the main claim and therefore it does not say anything on the topic of sustainability. And because the backing is not directly connected to the claim it cannot be a warrant. The distinction between backing and qualifier is also necessary: backing is different from a qualifier because backing focuses on the grounds, not on the claim.

The essays were coded using the coding scheme discussed above by two different coders. In the end this yielded reliable coding at the level of the characterization of claims, grounds of all categories, warrants, backing, rebuttals and qualifiers.

For each of the essays the number of aspects of argumentation were counted. The total amount of different categories of grounds were also determined. Finally, for each argument in the essay, the combination of aspects was counted according to Table 4.

Table 4.
Framework Used for Assessing the Quality of Argumentation[1]

Level of Argumentation	Combination of Aspects of Argumentation
Level 1	Claim and rebuttal
Level 2	Claim, grounds and warrant
Level 3	Claim, grounds, warrant and qualifier
Level 4	Claim, grounds, warrant and backing
Level 5	Claim, grounds, warrant and rebuttal
Level 6	Claim, grounds, warrant qualifier and rebuttal
Level 7	Claim, Grounds, warrant, backing and rebuttal/Qualifier

[1] Erduran & Simon, 2004

The combinations of aspects form a framework, each proceeding level has more aspects of argumentation and hence, a more sophisticated level of argumentation. Level three through five require some additional explanation because they al consist of four aspects. The common aspects are claim, grounds and warrant but they differ in the occurrence of either a qualifier, a backing or a rebuttal. Backing is more enriching to the quality of an argument with respect to level 3 argumentation because the backing adds value and reliability to the grounds and not, as in the case with the qualifier, adds reliability to the claim. If a student shows backing in an argument, the student shows that he has in depth knowledge on not only the claim, but also in the used grounds (Osborne, Erduran & Simon, 2004). The student shows in the case of level 4 argumentation that the grounds presented have different aspects and different conditions in which they contribute to the justification of the claim. A qualifier merely shows that the students understand the claim is not an absolute truth. Erduran et al (2004) argues that arguments with rebuttals are of better quality than those without because the individuals who engage in discussion without rebuttals remain epistemically unchallenged. The reasons for their belief are not questioned and are for that reason not as much thought through.

Validity, Reliability and Ethical Considerations

This study was primarily designed, implemented and analyzed by the author of this study. The first ethical challenge was the vested interest of the author with regard to the intervention. The involvement might detract from the internal validity of the study because the author was involved in all stages of the study. On the other hand, the author had the opportunity to collect in-depth data over an extended period of time. Several measures were taken into account throughout the project to lessen the chance of a skewed interpretation. These measures were:

i. The design of the project was evaluated multiple times by peers and third parties.
ii. The coding scheme is based on existing schemes used by other researchers (Erduran et al, 2004, Juntunen & Aksela 2014).
iii. The data analysis was carried out by two coders according to the Grounded Theory approach (Denscombe, 2010).
iv. The contextual frameworks are based on extensive literature review.

Another challenge of this study was that the group of participants was rather small. The generalization of the results is therefore impossible. The conclusions are not statistically representative because the standard deviations are very large. This made it also impossible to do additional statistical tests such as Fisher's exact test. However, within the context of the research question, appropriate conclusions may be drawn how the studied students changed their argumentative skills in the course of the life-cycle analysis.

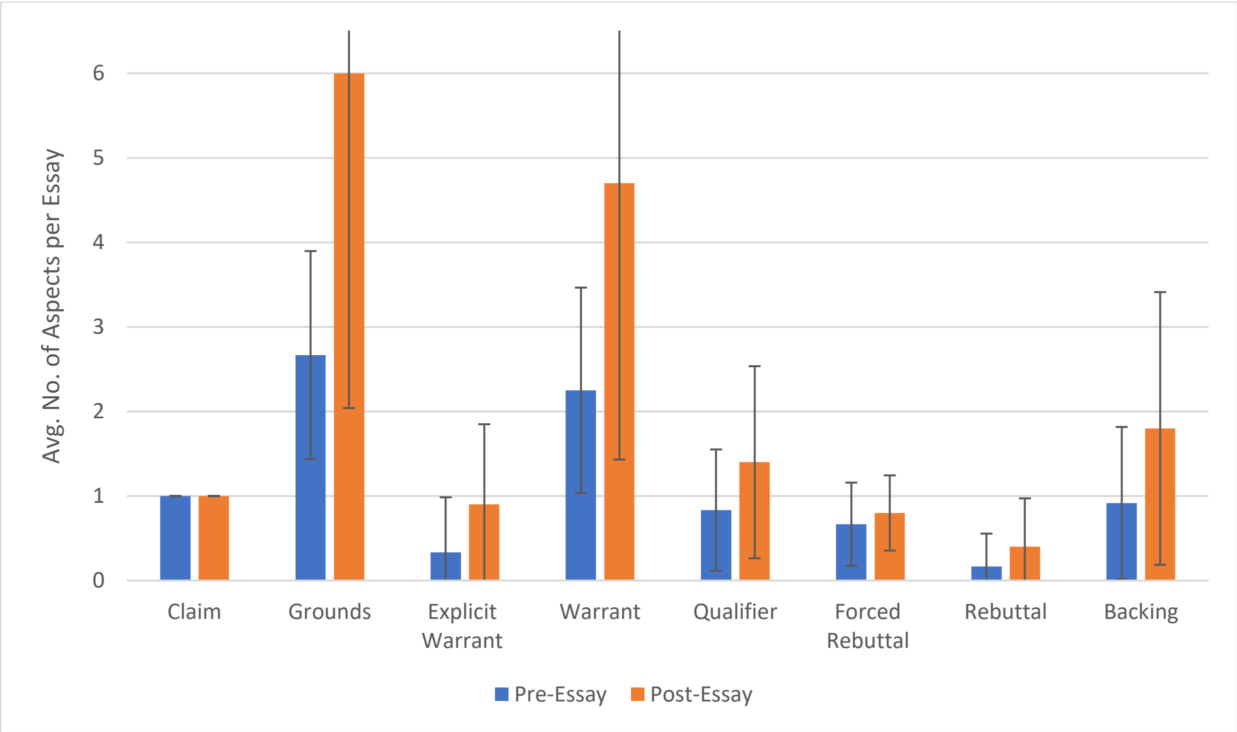
The anonymity of the students was ensured with cautious systematic data management. This caution also extended to data storage. The research data were not personally sensitive.

Results

Number of Aspects

The number of argumentation aspects in the pre- and post-essay were counted and analyzed on an individual level according to the scheme in the precious section. These results, with their average and standard deviation are supplied in appendix B. The average number of aspects per essay was determined and is presented in Figure 1.

Figure 1. The Average Number of Argumentation Aspects per Essay



The total number of claims in each essay is one, this is because every student pair had to begin their argumentative essay with what plastic they thought was most sustainable. And according to the coding scheme, there could be only one claim per essay. Seven groups chose paper cups, three groups chose starch-based plastic and two groups chose for polyethene. In the post-essay, five groups chose starch-based plastic and the other five groups chose Perspex. The average number of grounds per assay more than doubled in the post-essay.

The number of warrants, both implicit and explicit, also nearly doubled. This originates from the doubling of the average number of grounds. This shows in the same ratio of warrants and grounds found in the essays.

The average number of qualifiers per essay increased. The most used qualifier is stating that their elected plastic is the most sustainable out of the four available options (three options in the pre-test) they could choose from. In the post-essay the qualifiers were of a different nature. For example: “we have made biodegradability and whether it is recyclable a priority”. In this students’ point of view, the condition under which their claim holds true is: “if biodegradability and recyclability are indeed the most important factors that contribute to sustainability, our claim holds true”. The number of qualifiers not only increased, but also the nature of the qualifiers were different in the post-essay.

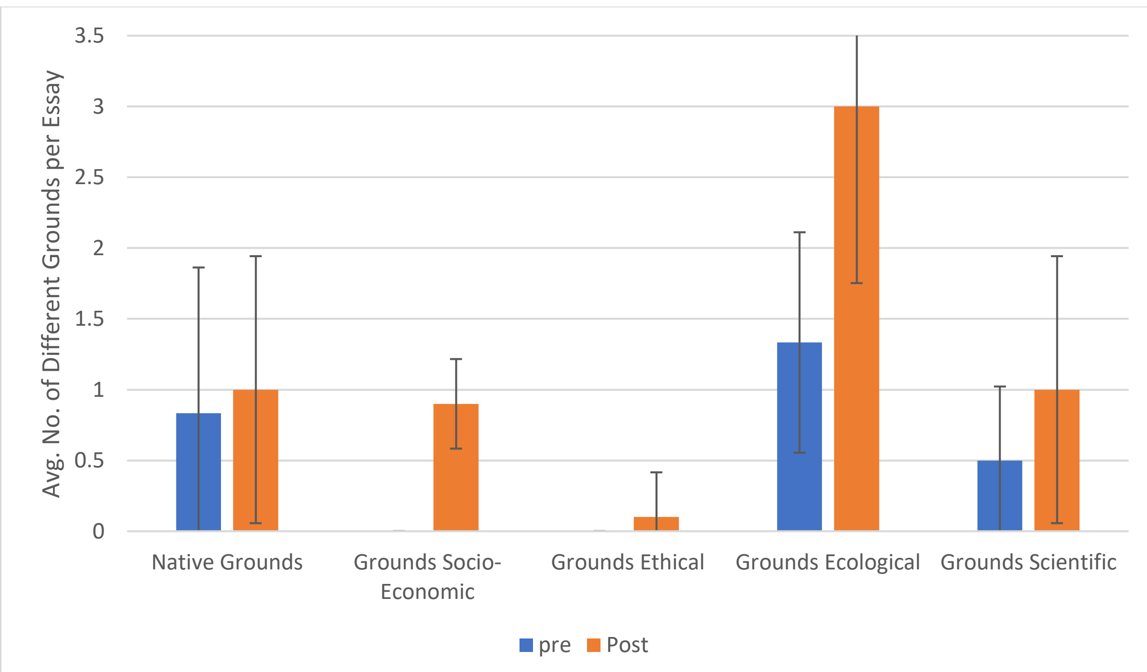
The average number of forced rebuttals stayed mostly the same. This was to be expected because the assignment forced the students to write down at least one counter-argument to their claim. The average number of spontaneous rebuttals increased, although not to a large extent. Two rebuttals in the pre-test as opposed to four in the post-test. This is twice as much but the increase is not reliable since the sample size was small.

The average number of backing increased. In both the pre-essay and the post-essay, one third of all grounds had backing. The students didn’t increase in the amount of backing for each presented ground. So, although the number of backing increased, the amount of times where students 'backed up' their grounds stayed the same.

Category Grounds

The number of different category grounds was counted for each essay. These results, with their average and standard deviation are supplied in appendix C. The average number of different grounds per essay was determined and is presented in Figure 2.

Figure 2. The Average Number of Different Category Grounds per Essay.

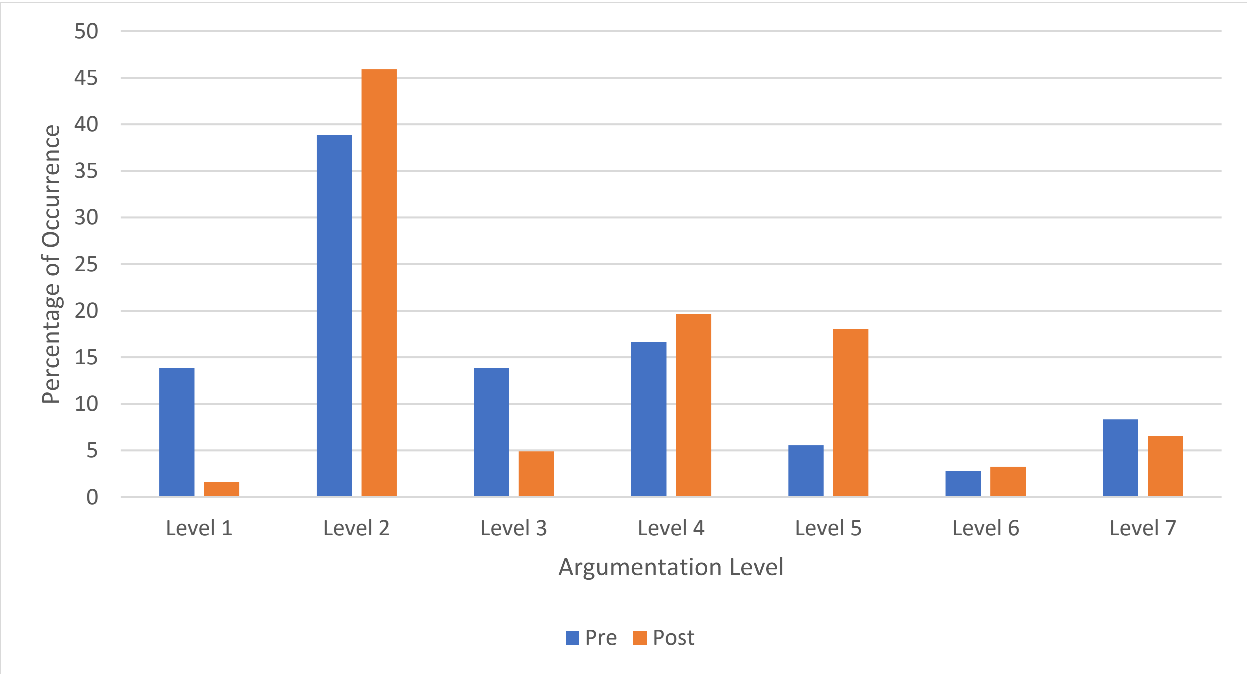


The results show that most groups of students present native grounds both in the pre- as in the post-test, ten accounts of native grounds were counted in both essays (the averages differ because the total number of essays in the post test was 10, and in the pretest 11). The native grounds in the pre-test were mostly statements on topics without an appropriate reference, or statements where it was very improbable that students had any knowledge on the topic. Some of the grounds were downright false. The majority of native grounds in the post-essay were statements like: “(we think) this is not important”. The arguments were opinions of the students which were not backed up in any way. No socio-economic grounds were found in the pre-argumentative essay, and nine instances were found in the post-test. Ethical grounds were mostly absent in the essays. The most common type of grounds were the ecological grounds. 50% of all grounds were based on the environment or the twelve principles of green chemistry. The average number of ecological grounds more than doubled resulting in the average of one scientific ground per essay in the post-test.

Combination of Argumentation Aspects

Finally, for each argument in the essay, the combination of aspects was counted according to Table 4. These Results, with their average and standard deviation are supplied in appendix D. The averages are expressed in percentages to show how the level of argumentation shifted from the pre- to the post essay, see Fgure 3. This was done because the number of grounds increased in the post-test. If these results were shown in the form of a nominal bar graph it would give the impression that students increased with respect to all levels, which is not the case.

Figure 3. The Level of Argumentation for each Argument Expressed in Percentages



Level 1 argumentation, a claim with a rebuttal, decreased in the post-essay. The decrease of level 1 argumentation is almost the same as the gain in level 5 argumentation (claim, grounds, warrant, rebuttal). No significant increase or decrease can be found for Level 2, 4 and 7 argumentations. Level 3 argumentation (claim, grounds, warrant, qualifier) decreased in the post-test. This may seem inconsistent with the average number of qualifiers increasing. If the number of qualifiers increased, level 3, 6 and 7 argumentations should likely also increase since these levels all include qualifiers. This irregularity can be explained as follows: what is seen in the data is that multiple qualifiers are presented in the same argument. The coding scheme counts this as one argument, one level 3 or one level 6 or one level 7 argumentation even though it has multiple qualifiers. The number of qualifiers can increase, even though the level of argumentation stays the same.

Conclusions and Recommendations

The research question was: "*What are the effects of students performing a life-cycle analysis on their argumentation skills regarding sustainability?*

The most notable effect of performing a LCA project was the doubling of the average number of grounds and warrants in the argumentative essays, as seen in Figure 1. This indicates that because of the plastic LCA, students learned to view a sustainability issue from many different angles and used this to formulate grounds based on many different aspects. Students have improved their content knowledge because the amount of grounds presented doubled, this has been previously linked to an increase in reasoning capabilities (Sadler and Zeidler, 2004). The increase of the number of grounds can be ascribed to the LCA. Most arguments in the post-essay used one of the metrics from the LCA.

The increase could also be ascribed to the amount of time students had to complete their essay. The students had thirty minutes to complete their pre-argumentative essay and an hour to complete the post-essay. For the next iteration of the project it would be an improvement to give the same amount of time to complete both essays.

The increase in grounds were mainly in the environmental- and scientific category which are considered in the study by Liu et al. (2010) as of high quality. The results are therefore not only quantitative but also a qualitative increase. One notable result was that although socio-economic grounds were almost absent in the pre-test, nine instances were found in the post-test. This increase can be attributed to the LCA. One of the analyzed metrics of the LCA was costs of production, thereby introducing costs/benefits as a valid aspect to assess sustainability.

The other notable result was that the amount of ethical grounds was very low. Students seemed somehow restricted of at least shy in expressing ethical grounds. Ethical grounds are still new and uncommon in the chemistry classroom. The LCA didn't include ethical aspects, this could be added. This result was also seen in the study of Juntunen and Aksela (2014).

Although the amount of warrants doubled, the ratio grounds/warrant did not change. This signifies that students already formulated a (implicit) warrant for each ground they had before they did the LCA project. The students probably did not increase in their ability to formulate a warrant since they were already capable.

The level of argumentation had a shift from low levels to higher levels, as seen in Figure 3. Although most levels remained more or less the same, the number of Level 1 arguments has reduced to a great extent. This finding is particularly encouraging as it suggests that after the intervention students developed the ability to correctly integrate rebuttals in their argumentation structure, this is seen by the increase of level 5 argumentation. This could also signify that students' ability to refute a counter-statement increased, since a rebuttal can in some ways be interpreted as a counter claim. The ability to formulate rebuttals in an argument was seen by erduran et al. (2002) as an argument of better quality. The other levels of argumentation showed no significant increase or decrease. This further substantiates that the promotion of argumentation skills is a difficult and multi-dimensional education goal (Sadler, 2004; Albe, 2008). Although from the results of this study, it is possible.

The LCA project could perhaps be improved by explicitly training students to formulate their arguments according to Toulmin's model. In this research, it was chosen not to do this because of two reasons: The first limitation was time constraints, it was impossible to implement this in the LCA project because the program of the two-day project was already filled. The second, more import reason is that by teaching the aspects of argumentation, the improvement in argumentation skills shown by students could be attributed to either performing the LCA or the teaching of Toulmin's logic.

Another possible limitation of this study is that the students were not looking for a consensus. If students were looking for a consensus, the students would perhaps listen more closely to each other which could lead to the use of more rebuttals and more qualifiers. This would help students to form more sophisticated arguments (Garcia-Mila, Gilabert, Erduran & Felton, 2013).

The developed coding scheme should be further validated. In the end, the scheme yielded reliable coding at the level of the characterization of claims, grounds of all categories, warrants, backing, rebuttals and qualifiers. This was after resolving the disagreements between the two coders. While Toulmin's model of argumentation is very useful for studying discourse and argumentation, the problems that this framework present should be acknowledged. In the extreme, perhaps another framework is needed to analyze argumentation such as posed by Walton (Walton, 1995). The ambiguous description on what counts as a claim, warrant, etc., makes the analysis of the data hard. The other problem is that the model only analyses contextual statements. The coders using this model sometimes need to fill in gaps and form assumptions on what the students were trying to say instead of what is actually written down. This damages the internal validity of the analysis. This last problem could be mostly resolved by interviewing the students after they write the argumentative essay.

Concluding, this study qualitatively shows that by doing a life-cycle analysis project the argumentation skills of students can increase. The students stated more grounds, most of which were of a higher level than before. And the level of argumentation had an upward shift, although not to a large extent. This implies that the life-cycle analysis project developed proves to be a useful approach to teach students about sustainability and in practicing argumentation in chemistry education.

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APPENDIX A The Twelve Principles of Green Chemistry

The Twelve Principles of Green Chemistry

No.	Theme	Explanation
1.	Prevention	It is better to prevent waste than to treat or clean up waste after its formed
2.	Atom Economy	Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
3.	Less Hazardous Chemical Synthesis	Whenever, practicable, synthetic methodologies should be designed to use and generate substances hat pose little or no toxicity to human health or the environment.
4.	Designing Safer Chemicals	Chemical products should be designed to preserve efficacy of the function while reducing toxicity.
5.	Safer Solvents and Auxiliaries	The use of auxiliary substances (e.g. solvents, separation agents, etc.) should be made unnecessary whenever possible and, when used, innocuous.
6.	Design for Energy Efficiency	Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conduced at ambient temperature and pressure.
7.	Use of renewable Feedstocks	A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.
8.	Reduce Derivatives	Unnecessary derivatization (use of blocking groups, protection/ deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.
9.	Catalysis	Catalytic reagents (as selective as possible) are superior to stoichiometric reagents
10.	Design for Degradation	Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.
11.	Real-Time Analysis for Pollution Prevention	Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
12.	Inherently Safer Chemistry for Accident Prevention	Substances and the form of a substance used in a chemical process should be choses to minimize the potential for chemical accidents, including releases, explosions and fires.

Note: Anastas, P. T., & Warner, J. C. (1998). Green Chemistry Theory and Practice, New York, NY, Oxford University.

APPENDIX B

Post-Test	Essay 1	Essay 2	Essay 3	Essay 4	Essay 5	Essay 6	Essay 7	Essay 8	Essay 9	Essay 10	Avg. No. of Aspects	Standard deviation
Claim	1	1	1	1	1	1	1	1	1	1	1	0
Grounds	4	7	5	9	5	6	6	9	4	5	6	3.9
Explicit Warrant	0	1	2	1	1	1	1	0	0	2	0.9	0.9
Warrant	4	4	2	7	4	5	5	9	4	3	4.7	3.2
Qualifier	1	0	1	3	2	0	2	2	1	2	1.4	1.1
Forced Rebuttal	1	1	1	1	1	1	0	1	0	1	0.8	0.4
Rebuttal	0	1	0	0	1	0	1	0	0	1	0.4	0.6
Backing	4	3	2	1	2	2	1	0	3	0	1.8	1.6

APPENDIX B (continued)

Pre-Test	Essay 1	Essay 2	Essay 3	Essay 4	Essay 5	Essay 6	Essay 7	Essay 8	Essay 9	Essay 10	Essay 11	Essay 12	Avg. No. of Aspects	Standard deviation
Claim	1	1	1	1	1	1	1	1	1	1	1	1	1	0
Grounds	5	2	2	4	2	3	3	2	3	0	3	3	2.7	1.2
Explicit Warrant	0	0	0	0	1		2	0	0	0	0	1	0.3	0.7
Warrant	4	2	2	4	1	3	1	2	3	0	3	2	2.3	1.2
Qualifier	0	0	1	1	2	1	0	1	1	0	1	2	0.8	0.7
Forced Rebuttal	1	0	1	1	1	1	0	1	0	0	1	1	0.7	0.5
Rebuttal	0	0	0	0	0		1		0	0	1		0.2	0.4
Backing	2	0	1	0	1	1	0	1	3	0	1	1	0.9	0.9

APENDIX C

Post-Test	Essay 1	Essay 2	Essay 3	Essay 4	Essay 5	Essay 6	Essay 7	Essay 8	Essay 9	Essay 10	Avg. No. of Aspects	Standard deviation
Native Grounds	2	2	2	2	0	0	0	1	0	1	1	0.9
Grounds Socio-Economic	0	1	1	1	1	1	1	1	1	1	0.9	0.3
Grounds Ethical	0	0	0	0	0	1		0	0	0	0.1	0.3
Grounds Ecological	1	4	2	5	3	2	4	4	2	3	3	1.2
Grounds Scientific	1	0	0	1	1	2	1	3	1	0	1	0.9

APENDIX C (continued)

Pre-Test	Essay 1	Essay 2	Essay 3	Essay 4	Essay 5	Essay 6	Essay 7	Essay 8	Essay 9	Essay 10	Essay 11	Essay 12	Avg. No. of Aspects	Standard deviation
Native Grounds	3	0	2	2	0	1	1	0	0	0	0	1	0.8	1.0
Grounds Socio-Economic	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grounds Ethical	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grounds Ecological	1	2	0	1	2	1	2	2	2	0	2	1	1.3	0.8
Grounds Scientific	1	0	0	1	0	1	0	0	1	0	1	1	0.5	0.5

APENDIX D

Post-Test	Essay 1	Essay 2	Essay 3	Essay 4	Essay 5	Essay 6	Essay 7	Essay 8	Essay 9	Essay 10	Avg. No. of Aspects	Standard deviation	Avg. Percentage
Level 1	0	0	0	0	1	0	0	0	0	0	0.1	0.3	1.6
Level 2	1	3	1	6	1	3	4	8	0	1	2.8	2.6	45.9
Level 3	0	0	0	1	0	0	0	0	1	1	0.3	0.5	4.9
Level 4	2	3	1	0	0	2	1	0	3	0	1.2	1.2	19.7
Level 5	0	1	2	1	2	1	1	1	0	2	1.1	0.7	18.0
Level 6	1	0	0	0	0	0	0	1	0	0	0.2	0.4	3.3
Level 7	0	0	1	1	2	0	0	0	0	0	0.4	0.7	6.6

APENDIX D (continued)

Pre-Test	Essay 1	Essay 2	Essay 3	Essay 4	Essay 5	Essay 6	Essay 7	Essay 8	Essay 9	Essay 10	Essay 11	Essay 12	Avg. No. of Aspects	Standard deviation	Avg. Percentage
Level 1	0	0	0	0	1	1	0	1	0	0	1	1	0.4	0.5	13.9
Level 2	3	2	0	2	0	1	0	0	0	0	3	1	1	1.2	38.9
Level 3	0	0	0	1	1	1	0	1	0	0	0	1	0.4	0.5	13.9
Level 4	1	0	0	0	0	1	0	1	2	0	0	1	0.5	0.7	16.7
Level 5	0	0	0	1	0	0	1	0	0	0	0	0	0.2	0.44	5.6
Level 6	0	0	1	0	0	0	0	0	0	0	0	0	0.1	0.3	2.8
Level 7	0	0	1	0	1	0	0	0	1	0	0	0	0.3	0.5	8.3