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THE VALUE OF INTEGRATING THE UN SUSTAINABLE DEVELOPMENT GOALS WITH A MICROSCALE EXPERIMENT FOR CHEMISTRY STUDENTS

The United Nation's sustainable development goals (UN SDGs) are a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity. Microscale chemistry kits already comply with many of the UN SDGs as they are greener, safer and more cost effective than traditional large-scale laboratory experiments. This qualitative study explored the value added for first-year chemistry students when the UN SDGs were integrated in a microscale experiment on industrial pollution: students were able to identify and explain relevant UN SDGS and communicate chemistry in context. Many students showed retention of the relevant UN SDGs two months after completing the experiment despite having no prior exposure to the UN SDGs. The majority of students felt that their laboratory experience was enriched by the inclusion of the UN SGDs, wished to learn more about the UN SDGs, and endorsed their inclusion as a graduate attribute.

Keywords
South Africa; chemistry; sustainable development; UN SDGs; microscale

Introduction

This study sought to fortify the curriculum of a first-year university chemistry course through the introduction of the United Nation's Sustainable Development Goals (UN SDGs). The motivation of this study was akin to many other chemistry initiatives which aim to cultivate ethical professionals and informed global citizens through the integration of the UN SDGs into their curricula(Mahaffy et al., 2017; O'Flaherty & Liddy, 2018). Furthermore, the preparedness of students to meet and explore the UN SDGs has risen to a desired graduate attribute in many tertiary institutions(Windsor, Rutter, McKay, & Meyers, 2014), including the tertiary setting for this study.

In this study, a microscale chemistry experiment was used to embed the UN SDGs into the curriculum. The focus of this study was to "nudge" student thinking about the UN SDGs by positioning chemistry concepts in the context of an experiment that simulates industrial pollution. The decision to integrate the UN SDGs had further advantages for students in that exploring chemistry in context is known to provide opportunities for meaningful learning in the laboratory (De Jong & Taber, 2014) and may even improve student attitudes and motivations(Bennett, Lubben, & Hogarth, 2007; Petillion, Freeman, & McNeil, 2019).

Literature Review

Chemistry's interest in sustainability and green alternatives began in the early 1990s(Anastas & Warner, 1998). This was due to the view that although chemistry has provided much for the advancement of humanity, chemistry has also made large contributions to global problems such as pollution and climate change(Matlin, Mehta, Hopf, & Krief, 2016). Global interests in sustainability also grew in this time, and in 2015 the United Nations General Assembly proposed seventeen international sustainable development goals for 2030 (see Figure 1). The UN SDGs are a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity. In the same year, there was a commitment from the International Union of Pure and Applied Chemistry (IUPAC) to aid in the attainability and sustainability of these goals. Since then, many international chemistry curricula have been developed to focus on green chemistry and sustainable education(Mammino et al., 2015; O'Flaherty & Liddy, 2018).

Figure 1. The seventeen UN SDGs taken from https://sustainabledevelopment.un.org/

Furthermore, chemistry education has invested heavily in 'chemistry in context' and 'systems thinking' approaches in the classroom and laboratory to support sustainable development(Bradley, 2019; Mahaffy et al., 2017; Ogino, 2019; Orgill, York, & MacKellar, 2019). Systems thinking in chemistry education (STICE) is more complex than chemistry in context as it involves exploring the effects of the interface of chemistry with other systems like "the biosphere, the environment, human and animal health" (Matlin, Mehta, Hopf, & Krief, 2016) along with the flow of molecules throughout system-oriented concept map extensions(Mahaffy, Matlin, Whalen, & Holme, 2019). Chemistry in context implies chemistry learning opportunities embedded in rich contexts that develop preliminary systems thinking(Mahaffy et al., 2017).

As the importance of sustainable development gained global traction, many tertiary institutions have focused on sustainability development as one of their graduate attributes. This has led to the active inclusion of the UN SDGs into many tertiary chemistry curricula(Windsor et al., 2014), whereas prior to this the focus was more general, including chemists' professional and environmental ethics(Brown & Wylie, 2006; Tafesse & Mphahlele, 2018).

However, gauging students' understanding of 'chemistry in context', that is, the complex systems with which chemistry interfaces, is no small feat(Talanquer, 2019), nor is gauging the students' uptake of graduate attributes(Kensington-Miller, Knewstubb, Longley, & Gilbert, 2018). For this reason, the SEEN framework proposed by Kensington-Miller *et al*. (2018) was used to loosely scaffold the intregration of the UN SDGs graduate attributes into the first-year chemistry course:

Specify: The graduate attribue of sustainable development was targeted. Students were made aware that they should identify relevant UN SDGs

Explain: Students were asked to explain their understanding of relevant UN SDGs

Embed: The UN SDGs were emebedded into a particular learning activity – a microscle chemistry experiment

Nudge: Students' thinking around the UN SDGs was broadened to beyond the laboratory environment through the context of the experiment – industrial pollution

There are many existing motivations for using microscale science experiments in chemistry laboratories, as they require less reactants and produce less waste, are safer, and are more cost effective(Mayo, Pike, Butcher, & Trumper, 1994; Singh, Pike, & Szafran, 2000). Microscale chemistry kits emerged in South Africa in the early 1990's and in 1996 these were keystone in the UNESCO Global Microscience Programme at school level. At the turn of the twenty-first century, IUPAC encouraged microscale experiments at the tertiary level(Bradley, 2001).

The researcher proposed a framework, in that microscale chemistry experiments have dual potential in terms of the UN SDGs (see Figure 2). It is clear that the use of microscale chemistry experiments supports the UN SDGs given their green nature (low health risks and low environmental impacts) but microscale experiments may also act as vehicles for the discovery and discussion of the UN SDGs themselves (see green arrow in Figure 2). Such a symbiotic relationship creates a space for teaching and learning of chemistry in context.

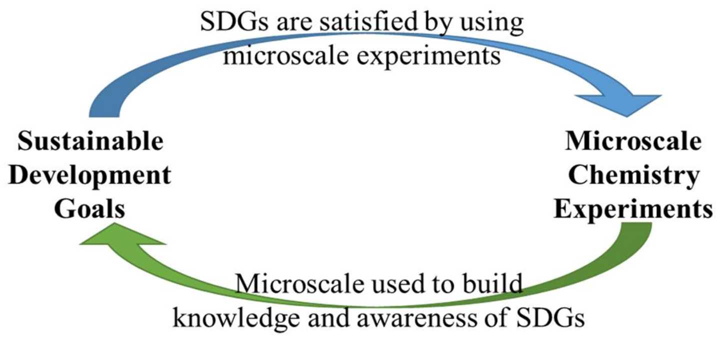

Figure 2. Framework showing the linkages between the UN SDGs and microscale chemistry.

Research Questions

Three research questions were developed to interrogate the value, for students, of integrating the UN SDGs within a microscale lab experiment on pollution. The study sought to add value to the students' laboratory experience by exposing students to the UN SDGs during a real-life laboratory experiment that touches on issues of concern for young scientists and ethical citizens.

1. Were students able to motivate for UN SDGS relevant to the to the microscale experiment?
2. How does the extent of exposure to the UN SDGs prior to the microscale experiment compare with the student retention of the UN SDGs after the experiment?
3. What are students' reflections on the value of integrating the UN SDGs with the microscale experiment?

Background

This study was done with first-year students enrolled in general chemistry on an extended programme BSc degree. All students are required to complete six laboratory experiments per semester. Each experiment is approximately three hours long and the majority of the experiments are microscale. Students usually complete the experiment individually and hand in a written report sheet at the end of each experiment. Students are expected to prepare for each experiment; this includes readings from the textbook, watching video links and conducting independent research.

Experiment

An existing microscale experiment was chosen for this study. The experiment was entitled "Simulation of industrial pollution" and was based upon the RADMASTE Practical Water Quality Testing microscale experiment. The aims of the experiment were to look at the production of pollution emissions and the effectiveness of two measures to limit air pollution and subsequent water pollution. Students formed very small (and thus harmless) quantities of sulphur trioxide gas using their microscale apparatus and micro-quantities of reagents, according to the reactions given below:

$$Na_2SO_3\ (s) + 2\ HCl\ (aq) \rightarrow SO_2\ (g) + H_2O\ (l) + 2\ NaCl\ (aq)$$

$$SO_2\ (g) + \text{atmospheric oxygen} \rightarrow SO_3\ (g)$$

When the sulphur trioxide gas reacted with water, the acidity of the water increases, as sulphuric acid was formed. This acidification was clearly visible to students as the universal indicator in the water alongside the "factory" changed from green (neutral) to red (acidic). Students attempted two measures to reduce the water acidification: attaching a chimney to the "factory" and then packing that chimney with CaO (see Fig. 3).

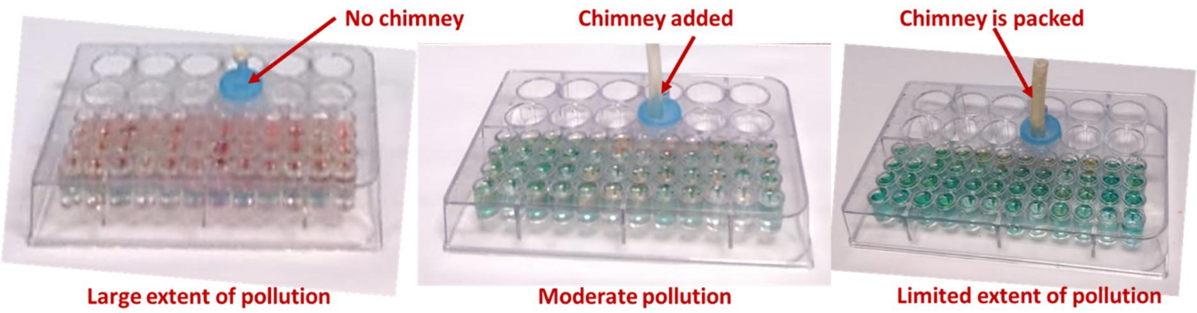

Figure 3. Controlling water pollution on a microscale.

This experiment was chosen as it already had implicit value for the discussion and discovery of the UN SDGs. The question, "Identify and explain the UN SDGs highlighted during this experiment", was added to the students' report sheets to support students in making their own explicit links between the microscale experiment and the UN SDGs. Students were required to do their own research on the UN SDGs prior to the experiment.

Methodology and analysis

The student body enrolled in general chemistry was large (n = 433) and diverse in term of gender, race and socio-economic background. This was a qualitative study and two different data collection methods were used: randomly selected copies of students' experiment report sheets (n = 25) and students' responses to a voluntary online survey (n = 52). Acknowledged weaknesses of the study were small sample numbers for report sheet analysis due to limited man-power and limited student participation due to the voluntary nature of the questionnaire. Due to anonymity, it is unclear if the sample is representative of the student population. Ethical clearance was obtained for this study NAS088.

The analysis of the report sheet was conducted by the researcher before the graded report sheets were handed back to the students. The analysis focused on the students' answers to the first question in the report sheet, "Identify and explain the UN SDGs highlighted during this experiment". The seventeen UN SDGs were used to deductively code the text, to answer research question one. Along with identifying the UN SDGs that students felt were relevant, the quality of the students' answers was also assessed, and relevant excerpts were selected for each of the commonly identified UN SDGs.

The voluntary Qualtrics survey was implemented two months after students completed the experiment, as the experiment fell towards the end of the semester and students had to complete their mid-year exam cycle. The online survey was primarily designed to explore research questions two and three with a blend of open and closed items (see Figure 4). Survey questions Q2 and Q4 only appeared based on the student's choices for survey Q1 and Q3 respectively.

Q1 – Remember Prac 5: Simulation of industrial pollution. You were asked to "Identify and explain the UN sustainable development goals (SDGs) highlighted during this experiment". Was this the first time you had been exposed to the UN SDGs?

- Yes
- No

Q2 - Before this experiment, how were you exposed to the UN SDGs?

Q3 - From memory, do you recall any of the UN SDGs that were highlighted in the Simulation of industrial pollution prac?

- Yes
- No

Q4 - Which UN SDGs were highlighted in the Simulation of Industrial Pollution prac? Please answer in your own words from your own memory, don't Google!

Q5 - To what extent do you agree with the following statements?

- I would like to learn more about the UN SDGs
- Doing a lab experiment which included the UN SDGs made it more meaningful for me
- Integrated and applied knowledge of the UN SDGs should be a University graduate student attribute

Q6 - What was the value of the Simulation of Industrial Pollution prac for you?

Q7 - If you have any other comments or questions regarding the prac or the UN SDGs, please respond

Figure 4. Qualtrics survey entitled "Industrial Pollution and UN SDGs"

Findings

Report sheets were numbered randomly (e.g. RS1-RS26) to ensure the anonymity of the students. In total, nine of the seventeen UN SDGs were identified by students as relevant to the experiment. The findings from the analysis of the students' report sheets revealed that many of the students motivated for two or more UN SDGs that they felt were relevant to the laboratory experiment on industrial pollution. The quality of these motivations was high, showing links to systems beyond the isolated chemical one that students were exploring in the laboratory (see Table 1).

Table 1. Identified UN SDGs and representative supportive reasoning

UN SDG	Representative Excerpts(s) from report sheets	Frequency (n)
3 GOOD HEALTH	"air pollution like SO_2 & NO_2 can cause respiratory diseases like chronic asthma, as it makes it hard for people to breathe" RS2	2
6 CLEAN WATER AND SANITATION	"Acid rain water will leach aluminium from soil and then flow into streams and lakes" RS2 "Acid rain which pollutes streams, lakes and other water sources by dropping the pH to below critical levels" RS24 "This experiment looks at the neutralisation of acid gases…to stop acid rain, which pollutes bodies of water" RS21	10
7 RENEWABLE ENERGY	"Focus should be placed on finding clean alternatives to fossil fuels used in industrial processes" RS13	2
9 INNOVATION AND INFRASTRUCTURE	"a properly built factory would produce reduced pollution and would be better for everyone" RS8	5
11 SUSTAINABLE CITIES AND COMMUNITIES	"people should try using public transport to reduce the emission of unwanted gases" RS11	3
12 RESPONSIBLE CONSUMPTION	"manufacturers need to place more emphasis on using resources wisely and in such a way that the health and well-being of the locals is not compromised" RS13	2
13 CLIMATE ACTION	"Climate change is increasing due to greenhouse gases… all countries agreed to work to prevent a global temperature increase" RS18 "Some pollutants perpetuate the problem of global warming, so extra care has to be taken by manufactures to reduce CO_2 and SO_2 footprints" RS13	12

14 LIFE BELOW WATER	"amphibians and fish will die due to this pollution" RS3 "acid rain will cause ocean acidification leading to the loss of coral reefs and the lives of many marine organisms" RS17	13
15 LIFE ON LAND	"Life of animals on land will be in danger as they depend on water that is not polluted, they will die also" RS3 "Acid rain will decrease the growth of plants" RS2	3

When evaluating the students' responses, all UN SDGs were permissible (as long as the student motivation, i.e. the links to the industrial pollution context, were explained adequately). In the sciences, there is often a wrong and a right answer, however, when viewing chemistry in context, the intricacies of the relationships and networks encourage a variety of interpretations. ***SDG 13 Climate Action, SDG 14 Life below water and SDG 6 Clean water and sanitation*** were the most frequently identified by students**.** The latter two findings were expected by the researcher as they represent direct impacts of air to water pollution. However, the identification of climate action (which can largely be described by climate change) as a highly relevant SDG was a finding that may suggest consequential and integrated thinking, indicative of the goals of 'chemistry in context'. It was also likely that the topical nature of climate change and global warming contributed to the maturity of students' contextual considerations and awareness.

As educators, one hopes for lasting effects beyond the confines of the classroom or laboratory. The responses to survey Q3 and subsequent Q4, showed that more than half of the students (29 of 52) recalled relevant UN SDGs after a period of two months. All 29 students were able to successfully discuss the relevant UN SDGs in their *own* words, for example, "Ensure there is enough clean drinking water for everyone and to ensure it is used efficiently and looked after for future generations".

The retention of the UN SDGs suggests true meaningful learning, especially in light of the fact that >60% of the survey respondents indicated that they had had **no** prior exposure to the UN SDGs before encountering them in the experiment. Of respondents who had indicated that they had prior experience with the UN SDGs, 12 respondents indicated the UN SDGs were included at high school level and 5 respondents indicated that their awareness stemmed from social media and news.

In Q6 of the online survey, students were asked to reflect on the individual value of merger of the UN SDGs with the industrial pollution microscale experiment. Two primary codes emerged from the data (see Table 2). '**Chemical Concepts**' was the first code that emerged and corresponded to key chemical ideas relating to the experiment: the application of acid-base gas-forming reactions, understanding limiting measures on reactions, and, the use of indicators to visualise pollution. Student's valued their chemical understanding, but more so, they were appreciative of the complexities around the chemistry system that they were able to explore, from this a second code emerged, '**Chemistry in context**'. It was clear that students found the experiment worthwhile and interesting, "I valued it so much, I did not know much about the UN SDGs, so it helped me to understand and want to know more about it".

Table 2. Coding of student responses to the personal value of the experiment

Code	Representative Quote(s) from Students	Frequency (n)
Chemical Concepts Students simulating pollution through appropriate reactions and learning about limiting measures	"To observe substances that cause pollution" "Learning how to implement effective methods to prevent water pollution" "It provided me with a better understanding as to how pollution works and its effects, even on such a small scale."	13
Chemistry in context Students appreciating the interface of chemistry with other systems. Chemical systems are not examined in isolation, the far reaching effects of chemical phenomena are acknowledged	"One the reactions corroded my combo plate, so it really opened my eyes to the extent of the damage these pollutants cause for our planet" "It opened my eyes to how the world is at the current moment and the impact one individual can make to the environment" "it helped me remember that we need to take care of the world"	16

Further probing the value of the integration of the UN SDGs with the microscale experiment revealed that 73% of the respondents either agreed or strongly agreed that the merger of the UN SDGs with the laboratory experiment made it more meaningful for them (see orange in Figure 5). Students were responding to statements on a 5 point Likert scale (see Q5, Figure 5)

The other two statements in survey Q5 assessed students' desire to know more about the UN SDGs (see blue in Figure 5) and their opinion on the inclusion of the UN SDGs as graduate attributes (see green in Figure 5). Again, the majority of respondents concurred with the statements given. Additionally, students were given an opportunity to comment or put forward their own questions at the end of the survey. Several students asked questions such as, "What is the university doing to achieve or integrate with these sustainable development goals?" or asked whether there were organisations that students could join to reach these goals.

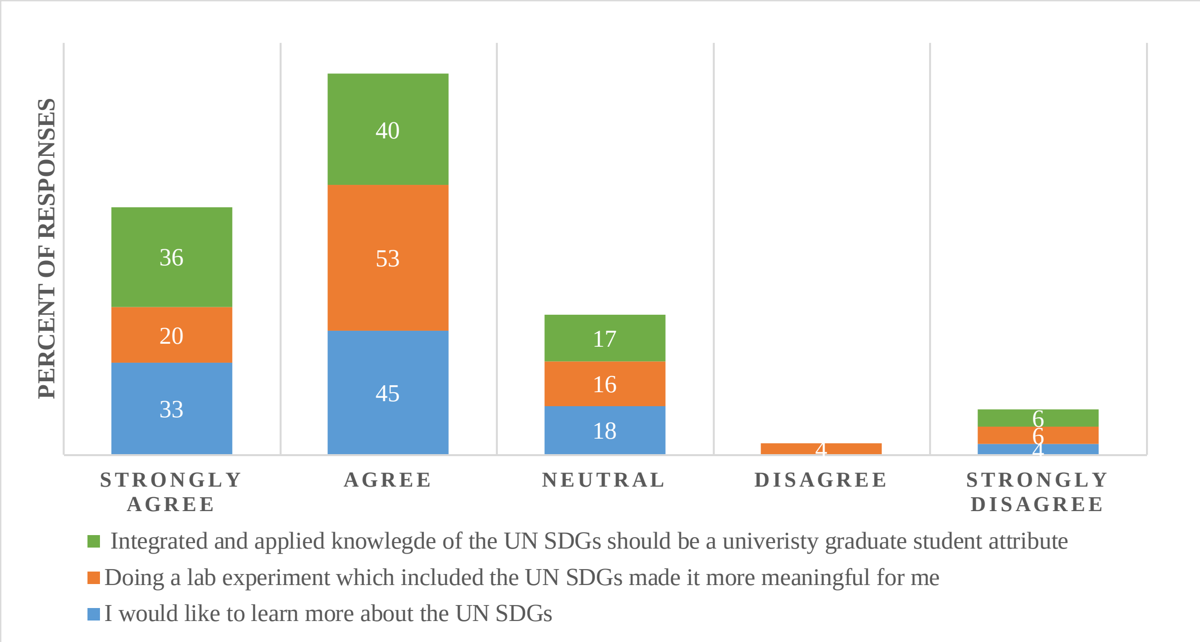

Figure 5. Likert scale responses to Q5 from the Qualtrics survey

Discussion

Petillion *et al.* (2019) introduced preliminary systems thinking in introductory chemistry modules using the UN SDGs as a thematic or anchoring framework. Instead, in this paper, students were prompted to map relevant UN SDGs onto a microchemistry experiment on industrial pollution according to the SEEN framework. The first research question queried whether first-year students would be able to identify and explain the UN SDGS relevant to the microscale experiment. From the analysis of the students' report sheets it was clear that students were able to identify a wide selection of UN SDGs and motivate their relevance to the experiment appropriately.

Even though this study was small and qualitative in nature, similar findings to Petillion *et al.* (2019) emerged in terms of students thinking beyond the isolated chemistry system to seeing chemistry in context i.e. in relation to the systems around it. Specifically, evidence of thinking about chemistry in context may be in the students' overarching concern for climate change as a result of chemical, industrial and environmental system interactions.

In attempting to answer the second research question, the self-reported exposure of first-year chemistry students to the UN SDGs prior to the microscale experiment was poor. This was an unanticipated finding as the UN SDGs were proposed in 2015, after a global 'Decade of Education for Sustainable Development'. Additionally, a large scale CAPS document analysis by Tsakeni (2018) revealed many opportunities for the inclusion of sustainable development education in physical sciences in South African schooling. A possible reason for this disjunction may be that learners are exposed unknowingly at school level, without the links from their curriculum to the UN SDGs being made explicit. An alternative argument may be the pressure on teachers to complete the curriculum may result in the side-lining of the UN SDGs. On a positive note, the ability of students to recall and accurately describe the

UN SDGs highlighted in the experiment after two months indicates the successful integration of the UN SDGs into the laboratory curriculum and into the students' long term memory.

The final research question sought to probe the value, for students, of integrating the UN SDGs with the microscale experiment. Value for students manifested in the open items of the questionnaire, as the *application* of 'chemistry concepts' in context, this corresponds to the findings of De Jong and Taber (2014). Furthermore, the context led to the exploration of systems that interface with the chemical one i.e. 'chemistry in context'. Students reported that they found this aspect particularly interesting and kindled a desire to know more about the UN SDGs, again this corresponds to findings of positive attitude and motivation as described by both Bennett *et al*. (2007) and Petillion *et al*. (2019).

Students' zeal in wanting to know more about the UN SDGs and the attachment of meaningful learning to the integration of the UN SDGs was corroborated by the Likert scale findings. Furthermore, the students' agreement with the UN SDGs as a university graduate attribute suggests how valuable the experience was to them and how open these young citizens are to the call for global action.

The Specify, Explain, Embed, Nudge (SEEN) framework efficiently allowed the researcher to integrate the graduate attribute of sustainable development into the microscale experiment. The topic of the microscale experiment, industrial pollution, allowed students to explore both chemistry concepts and chemistry in context. As proposed by the researcher, microscale experiments can have a successful dual purpose in achieving the UN SDGs as they epitomise green chemistry in terms of quantities of reagents, waste and safety but are also versatile vehicles for the integration of rich learning contexts and subsequently the UN SDGs into laboratory curricula.

Conclusion

The integration of the UN SDGs into the microscale experiment was necessary as more than 60% of the first-year students indicated that they had had no prior experience with the UN SDGs. Many practitioners may find themselves with learning materials that have subtle links to the UN SDGs and, with a little extra effort, these learning materials could be used according to the SEEN framework for students and learners to explore sustainable development and begin to develop thinking that explores chemistry in context. It is clear that the majority of students felt that the microscale experiment was enriched by the incorporation of the UN SDGs. By adding further value to microscale experiments, this study was able to contribute to meaningful learning for first-year chemistry students. There were qualitative findings of student interest as students engaged with sustainability, which is a graduate attribute that is sorely needed in the 21st century.

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