Al-imad Journal of Humanities and Applied Sciences (AJHAS)
مجلة العماد للعلوم الإنسانية والتطبيقية
ISSN: 3106-0323
Volume 2 – Issue 1 – 2026
Pages 99-108

Acid-Base Ideas Among Libyan Undergraduate Seniors: A Phenomenological Approach

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أفكار طلبة مرحلة السنوات الأخيرة الليبيين عن الأحماض والقواعد: تقصٍّ فينومينولوجي

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Received: 03-12-2025; Accepted: 01-01-2026; Published: 01-02-2026

Abstract:
Exploring students' ideas about a particular concept is the first step in the process of constructing valid diagnostic instruments such as concept inventories and multi-tier tests. This exploratory qualitative study, utilizing a phenomenological approach, aimed to investigate Libyan undergraduate chemistry seniors' conceptual understanding and identify misconceptions regarding acid-base chemistry. The study was conducted at a public university in eastern Libya, involving five senior chemistry majors who had completed Analytical Chemistry (I). Participants engaged in a guided-inquiry, project-based learning experience where they designed laboratory experiments and reported their findings. Data collection involved multiple methods, including observations during discussions and laboratory sessions, a demographic questionnaire, an open-response test with a confidence-level reporting section, and in-depth interviews. Thematic analysis was employed to identify patterns and clusters of ideas from transcribed interviews. The results revealed several significant misconceptions, some of which had not been previously documented in literature. Notable findings included participants' inability to draw titration curves for weak acid-weak base systems, confusion between hydronium ion concentration and pH values, and the misconception that an indicator acts as a catalyst. Furthermore, some students incorrectly defined Brønsted acids based on electron gain rather than proton transfer. Participants reported that the hands-on activities and the project-based approach significantly improved their understanding and prepared them for their final reports. The study concludes that identifying these specific misconceptions is vital for educators to improve teaching strategies and develop more effective diagnostic assessments.

Keywords: Chemistry education, teaching acid-base chemistry, Upper-division undergraduates, students' pre-concepts, project-based learning.

الملخص
يعتبر استكشاف أفكار الطلاب حول مفهوم معين هو الخطوة الأولى في عملية بناء أدوات تشخيصية صالحة مثل اختبارات المفاهيم والاختبارات متعددة المستويات .هدفت هذه الدراسة النوعية الاستكشافية، باستخدام المنهج الفينومينولوجي (الظواهري)، إلى تقصي الفهم المفاهيمي لطلاب الكيمياء الليبيين في السنة النهائية وتحديد المفاهيم الخاطئة المتعلقة بكيمياء الأحماض والقواعد .أجريت الدراسة في جامعة حكومية بشرق ليبيا، وشملت خمسة طلاب من تخصص الكيمياء ممن أنهوا مقرر الكيمياء التحليلية .(1) انخرط المشاركون في تجربة تعلم قائمة على المشاريع والاستقصاء الموجه، حيث قاموا بتصميم تجارب مختبرية وإعداد تقارير عن نتائجهم .تضمنت عملية جمع البيانات طرقاً متعددة، شملت الملاحظات أثناء جلسات النقاش

والمختبر، واستبياناً ديموغرافياً، واختباراً مفتوح الاستجابة يتضمن قسماً لتقرير مستوى الثقة، ومقابلات متعمقة .تم استخدام التحليل الموضوعي لتحديد الأنماط ومجموعات الأفكار من المقابلات المنسوخة .كشفت النتائج عن وجود العديد من المفاهيم الخاطئة الهامة، والتي لم يتم ذكر بعضها سابقاً في الأدبيات العلمية . وشملت النتائج البارزة عدم قدرة المشاركين على رسم منحنيات المعايرة لأنظمة الحمض الضعيف والقاعدة الضعيفة، والخلط بين تركيز أيون الهيدرونيوم وقيم الأس الهيدروجيني(*pH*) ، والمفهوم الخاطئ بأن الكاشف يعمل كعامل حفاز .علاوة على ذلك، عرف بعض الطلاب أحماض برونستد بشكل غير صحيح بناءً على اكتساب الإلكترونات بدلاً من انتقال البروتونات .وأفاد المشاركون بأن الأنشطة العملية والنهج القائم على المشاريع أدى إلى تحسين فهمهم بشكل كبير وإعدادهم لتقاريرهم النهائية .تخلص الدراسة إلى أن تحديد هذه المفاهيم الخاطئة المحددة أمر حيوي للمعلمين لتحسين استراتيجيات التدريس وتطوير تقييمات تشخيصية أكثر فعالية.

الكلمات المفتاحية :تعليم الكيمياء، تدريس كيمياء الأحماض والقواعد، طلاب المرحلة الجامعية المتقدمة، المفاهيم المسبقة للطلاب، التعلم القائم على المشاريع.

Introduction

Acid-base chemistry topics are common in both chemistry and biology core courses. Topics like titrations and buffers are essential in general chemistry, biochemistry, and organic chemistry (Cartrette & Mayo, 2011). To improve students' conceptual understanding of chemistry topics, many studies have been conducted (Tümay, 2016; Schmidt, 1997; Abdugadar, 2019). In order for students to construct meaningful scientific schemas, their background information should be intact. Every learner has unique background knowledge on which to construct new learning according to constructivism, the theory of learning (Cobern, 1993).

Preliminary studies can help pilot students' misconceptions to be later addressed in teaching or used in developing valid instruments, such as multi-tier tests or concept inventories (Prince et al., 2009). The importance of our study is to help educators and practitioners design instruments that precisely measure students' understanding and misunderstandings. Any misconceptions revealed could be incorporated as distractors later in the stage of developing diagnostic tests (Herrmann-Abell & DeBoer, 2011). When revealed, misconceptions could be a great introduction to a particular topic taught in classrooms. Some studies suggest using misconceptions as plausible distractors for multiple-choice questions used by instructors (Lamichhane et al., 2018). Our ultimate goal is to help practitioners use our findings not only for testing purposes but also for teaching new materials to prevent misconceptions. Project-based learning helps students improve their problem-solving skills and has a positive influence on students' understanding (Chistyakov et al., 2023).

Theoretical Framework

Phenomenology was the philosophical stance used in our study to obtain deep insight and focus on every particular participant. Phenomenology is a philosophy of knowledge and a qualitative research approach that is popular in education. It studies the meaning of a lived experience that several individuals have shared (Anderman & Anderman, 2009; Creswell et al., 2007). Phenomenology is used to describe what participants share in common as they experience a phenomenon (Creswell, 2013).

Research Questions

1. What is the participants' understanding of acids and bases?
2. How do students perceive the guided-inquiry approach used in this study in terms of improving their understanding of acids and bases?

Methods

Participants

The target population was undergraduate chemistry-major students who had finished taking the course Analytical Chemistry (I) along with its laboratory section on acid-base chemistry. Students who had completed this course were the best fit for this study because they had developed the content knowledge required to understand all the terms used by the researchers. The accessible population consisted of students enrolled in the course "Projects in Chemistry," which is a designated course where students work for two academic terms to submit their graduation report. Their findings were then presented to the chemistry department for the fulfillment of a Bachelor's degree in Science. All participants were chemistry major seniors who had taken the analytical chemistry course described above. All participants chose to work on an acid-base project. We chose this course to implement our project-based learning treatment because of the small class size and the readiness of the seniors for this type of inquiry-based, scaffolding learning.

The enrollment rate of the "Projects in Chemistry" course was low (6 students), whereas the capacity of the course is fifteen. Usually, students in this course are assigned different projects where they work in pairs or in groups of three. However, since there were only six enrolled students, we preferred to assign them only one main topic with three different subtitles in order to engage them in one project-based learning experience. All of these subtitles were acid-base inquiry assignments covering the topics of buffers, indicators, titrations, and pH meaning and calculations. Only 5 of the students chose to participate in this preliminary study; 4 of them were female and one was male; all of them had a GPA higher than 3 on a scale of 4.

Recruitment

At the beginning of the second term, students enrolled in the "Projects in Chemistry" course were asked to participate in the current study. Consent for using student data was obtained using a consent form. Participation in the study was voluntary and confidential. The study took place outside of instruction time, and participation was not associated with any grades.

Setting

The setting for this phenomenological study was a public university in the eastern part of Libya. The College of Science at this university is one of the largest colleges in the country, housing approximately 2,000 students.

Instrumentation

Research Methods Course:

We created a 2-credit hour course that introduced students to academic writing. All chemistry major students who had finished two years in the program were eligible to enroll. This course remained open after the study concluded and became mandatory for the fulfillment of the degree. This course provided the academic assistance students needed to write their graduation project reports. Ten students enrolled in this course, and only 6 of them subsequently enrolled in the "Projects in Chemistry" course, the target course for this current study.

Reading Assignments:

After finishing the research methods course, all students enrolled in the "Projects in Chemistry" course were assigned the same chapters from their textbook covering acid-base topics, including acid definitions, acid-base titrations, indicators, salt hydrolysis, titration curves, and the pH scale in a scaffolding manner.

Observations:

The first observation was conducted right after assigning the first reading. The students were engaged in a discussion session about their reading. The second observation was done while the students were in the laboratory performing several titrations. The aim of these observations was to evaluate the students' prior knowledge regarding acid-base chemistry topics and perform a quick diagnosis regarding the presence of any misconceptions. Additionally, we explored the areas where participants had difficulties to incorporate these findings into the construction of the interview questions and pre-laboratory lectures.

Consent Form:

Participants were asked to sign a consent form to allow us to use their responses in our study. The form explained the study's purpose and informed participants that their participation was valuable and voluntary, with no associated risks. It stated they could withdraw at any time without affecting their project or grades.

Demographic Questionnaire:

Participants were given a demographic questionnaire to help describe the sample and control for other factors that might affect their responses, such as age, sex, and background knowledge.

Open-Response Test:

This test consisted of five parts based on the learning difficulties identified during observations. The language used was tailored for chemistry majors. The test was written by a chemistry professor with over twenty years of experience, and two additional instructors reviewed it before administration. Furthermore, each item included a section for students to report their confidence level. This allowed wrong responses due to misinformation to be distinguished from those due to misconceptions. More attention was given to incorrect responses to better identify common misconceptions. Correct answers were not categorized, as they could result from a lucky guess rather than scientific conception (Huddle & Pillay, 1996).

In-depth Interview:

This interview inquired about students' responses and how they derived their answers in the open-response test. Interviews were audio-recorded and later transcribed to explore their ideas on acids and bases.

Final Interview:

Students described their experience in the study, including the project completion and testing process. They were asked for recommendations and if they found the reading assignments relevant. Confidentiality was maintained throughout; all raw data were kept in a locked file cabinet.

Procedures

After approval from the UOB-Al-Marj Institutional Review Board, students were given reading assignments. A discussion session followed two weeks later. Two laboratory sessions were held where students attended pre-laboratory lectures and performed titrations. Two observations took place: one during the discussion and one in the laboratory. The project was a guided-inquiry, practical type where students designed experiments and reported findings. A purposive sample of 5 seniors worked on acid-base chemistry. They attended two pre-laboratory lectures and completed three reading assignments before performing the titrations.

A demographic questionnaire was provided after the consent form was signed. Next, the open-response test was administered. To further explore understanding, an in-depth interview was conducted immediately after the test to detect conceptual misunderstandings. A final interview was conducted one week later to inquire about perceptions of the experience. A final discussion session was held after the study concluded to clarify any confusion.

Data Analysis

Data collection for this phenomenological study involved in-depth and multiple interviews, observations, and documents. Interviews were transcribed, and significant sentences were highlighted as direct quotes to provide a general understanding of the participants' experiences. In the interpretation phase, the inquirer developed large clusters of ideas from participant quotes into themes (Braun & Clarke, 2006). Qualitative data were analyzed using thematic analysis. QSR International's NVivo 12 was used to transcribe interviews, and quotes were used to draw final conclusions (Bazeley, 2002; Given, 2008). Trustworthiness was assured by the follow-up interviews where students confirmed their test answers.

Results

Analysis of Themes

The ideas and patterns found across the data are summarized in Table 1. The criteria for identifying misconceptions were based on the in-depth interviews with the participants. Specifically, if a participant provided the same incorrect response multiple times, it was categorized as a misconception for this study. Additionally, a response was labeled a "misconception" if it had been cited in the literature as a common conceptual error. In this study, many misconceptions were exposed even without asking specific questions designed to trigger them. Furthermore, the confidence levels reported by participants after each question helped identify these misconceptions; an incorrect response accompanied by high confidence was considered a clear misconception in this study.

Table 1. Themes and Corresponding Research Questions

Themes	Goal/Purpose or Research Questions
1. Wrong responses	**Q1:** Students' ideas and understanding?
2. Misconceptions	**Q1:** Students' ideas and understanding?
3. Students' experiences with the project-based learning graduation project.	**Q2:** The effect of the project they participated in?
- The effect of the interview and the open-response test.	
- The effect of the reading assignments and the pre-lectures.	
- The effect of hands-on activities on their understanding.	

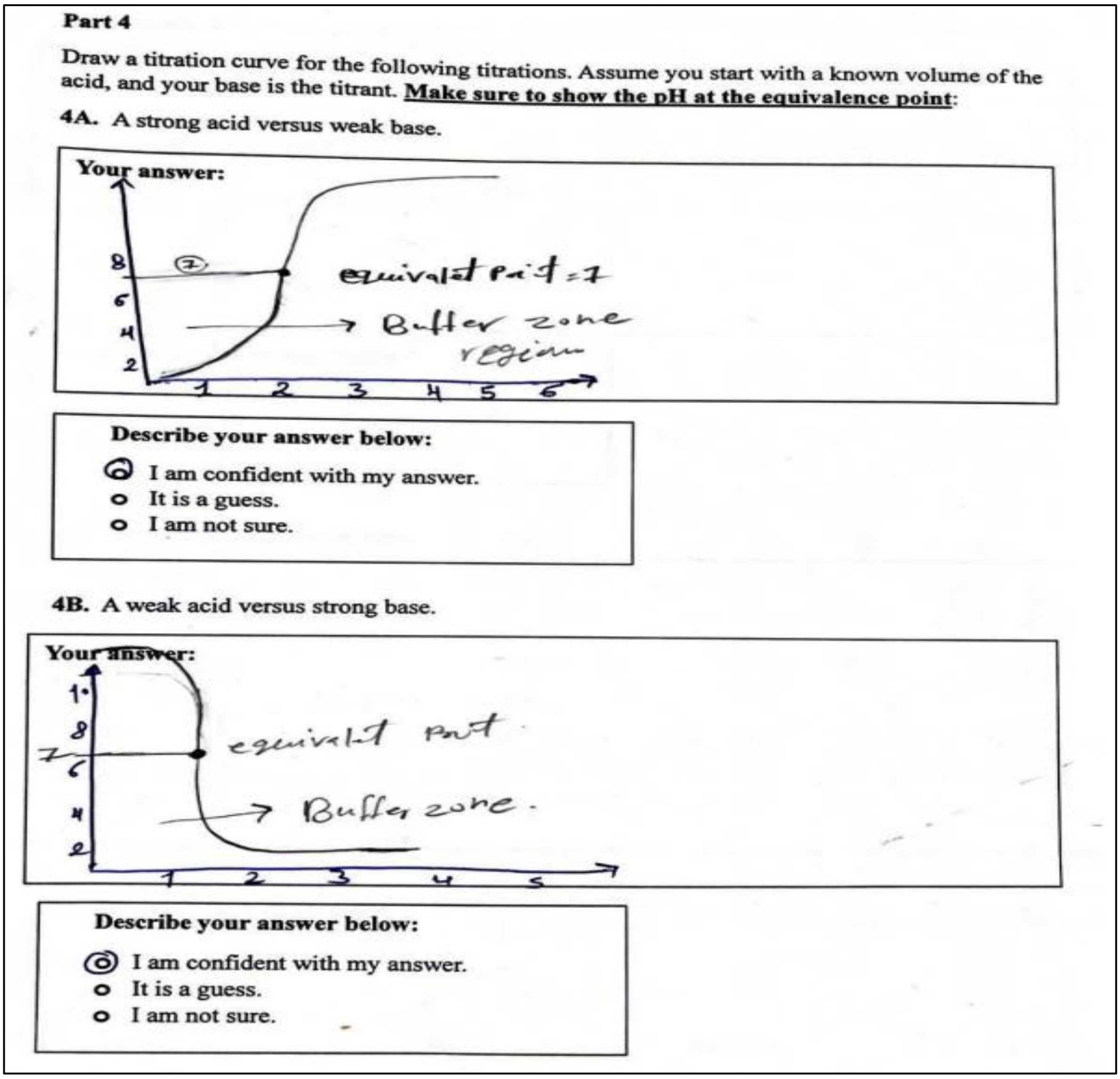
Wrong Responses

None of the five students were able to draw the titration curve for a weak acid-weak base titration. They stated that they had never been taught how to draw such a curve. Even in the reading assignments provided at the beginning of the project, this particular titration was not mentioned. Furthermore, the participants failed to define the term "indicator" accurately; the

only definition they provided was that an indicator is a substance that changes color. All participants failed to explain the chemical mechanism behind this color change.
In addition, none of the students named a weak base. All of them were familiar with weak acids and strong acids and bases. We think that instruction make this gap in students' understanding to titrations. In addition, the excessive representation of sodium hydroxide, acetic acid and hydrochloric acid makes students limit titrations in general and analytical chemistry courses to only these options. The students were able to successfully name a weak acid, strong acid, and a strong base. All of the students failed to visualize a solution of a pH of 0 and another with a pH of 14. They could not visualize the presence of such solutions since this kind of calculations have never been covered in lectures. The participants also failed to determine the exact pKa and the exact equivalence point on the titration curve even after the first introductory pre-lecture.

Misconceptions

Table 2 provides a summary of misconceptions found among the five senior students who participated in this preliminary qualitative study. One student incorrectly defined Bronsted acid as it is a substance that gains electrons to convert from state HX to X-. She said that HCl is a Bronsted acid because the chloride gains electrons and became an anion (Cl-). Another student said the difference between weak acids and strong acids in titrations is that the peak of the sigmoidal shape starts at a lower pH in case of strong acids. This misconception was confronted by asking the student to calculate the pH at the beginning of the titration in case of 0.10 M of formic acid and then for acetic acid. Another student said that time is needed for weak acid titrations since weak acids consume more time to neutralize.
One student reported that she cannot calculate the molar concentration of hydronium ion in an acidic solution with a pH of zero because she cannot fill the ka expression equation with a molar concentration of 0. This student confuses the molarconcentration of hydronium ion with the pH value. Another student reported that acids have higher pH values than bases. It seems that this student confuses the term pH with the concentration of the hydronium ion.
One more misconception was that an indicator in a titration procedure is a catalyst since at the end of the reaction the indicator is retained. This misconception was not mentioned in literature. Another misconception regarding the use of indicators was that two indicators can be used together in the same titration. The last misconception revealed by this study was that the starting point in a titration on the pH scale is about 10 for a weak acid/strong base titration. All of the students flipped the sigmoidal shape when they were asked to replace a strong acid in a titration with a week acid. These responses were scored as misconceptions relying mainly on the interview. Four of the participants held this misconception. They thought if a strong acid is present, the titration should start about a pH of 2.0, for example, and if a strong base is present instead, the initial pH should be basic which is a misconception. Figure 1 represents a student response regarding this misconception.



Part 4

Draw a titration curve for the following titrations. Assume you start with a known volume of the acid, and your base is the titrant. **Make sure to show the pH at the equivalence point**:

4A. A strong acid versus weak base.

Your answer:

Describe your answer below:

- I am confident with my answer.
- It is a guess.
- I am not sure.

4B. A weak acid versus strong base.

Your answer:

Describe your answer below:

- I am confident with my answer.
- It is a guess.
- I am not sure.

Figure 1. A student's answer comparing two different titration curves.

Students' Experience with the Project

The participants expressed significant gratitude regarding their involvement in the study. According to three of the participants, their overall participation—including the guided-inquiry laboratory experiments, the reading assignments, and the pre-laboratory lectures—greatly enhanced their preparation. Furthermore, they highlighted that the immediate online feedback they received whenever they had questions made them feel more confident and better prepared to submit their final projects.

The Interview Effect

The in-depth interviews played a crucial role in clarifying several terms and concepts that students had previously used inappropriately. During the interview sessions, many students revised their responses, replacing naive ideas with more scientifically accurate conceptions about acids and bases. For instance, one student initially believed that two indicators could be used simultaneously in a single titration. This misunderstanding arose because she had encountered a titration curve in her reading assignment that depicted two indicators changing colors in different pH regions. This misconception was identified and addressed through detailed explanation during the interview process.

Table 2. Misconceptions Identified in the Study

Misconception	Number of Students (n=5)
1. The conjugate base has a minus sign, proving that an acid is a substance that gains electrons to become X^-.	1
2. Titration curves of weak acids must start at a pH greater than 3.	4
3. Weak acids require more time to neutralize.	3
4. Confusion between the molar concentration of $[H^+]$ and the pH value.	5
5. Two indicators can be used simultaneously in a single titration.	2
6. The sigmoidal curve is flipped for a weak acid-strong base titration.	4

The Effect of Introductory Lectures and Reading Assignments

In addition to the impact of the interviews, participants appeared to value the introductory lectures more than the independent reading assignments. This suggests that students are accustomed to a traditional learning fashion, where the instructor serves as the primary source of information. Furthermore, students reported utilizing the internet when assigned textbook readings. They expressed a preference for self-directed learning and highly appreciated the discussion sessions held with their classmates during laboratory time.

The Effect of Hands-on Activities on Understanding

All participants reported that performing titrations significantly improved their understanding of acid-base chemistry concepts. The positive influence of hands-on activities on student interest and understanding has been well-documented in previous literature (Holstermann et al., 2010; Prince et al., 2009). One participant noted that the laboratory work stimulated deeper critical thinking, stating: *"Doing hands-on activities raised some questions that I did not think of while I was designing the experiment. Reading about titrations differs significantly from actually performing them."*

Conclusions

The qualitative approach employed in this study does not allow for definitive claims regarding the effectiveness of the guided-inquiry experience; this represents a common limitation inherent in qualitative research. However, the primary goal of this study was not to generalize findings to a broader population, but rather to investigate students' conceptual ideas regarding acid-base chemistry and to facilitate the construction of a valid diagnostic instrument for future mixed-methods research. Exploring students' ideas remains fundamentally beneficial for educators, as reporting specific misconceptions assists instructors in refining both their teaching methodologies and their assessment strategies.

In the existing literature, quantitative and mixed-methods approaches have proven to be valuable tools for constructing valid assessments, such as multi-tier tests and concept inventories. Interestingly, many misconceptions commonly reported in previous studies were not present in our participant sample. For instance, the participants in this study did not exhibit the typical confusion regarding acid-base equilibria often found in the literature. Conversely, this study revealed several novel misconceptions that had not been previously documented, which may be attributed to the scarcity of such pedagogical research in this specific geographical region.

The ultimate aim of this research is to enable educators to use the revealed misconceptions as a pedagogical starting point to help students avoid alternative conceptual frameworks. By dedicating instructional time to discussing these misconceptions, educators can facilitate the construction of scientifically accurate mental representations. Furthermore, these findings serve as a critical foundation for developing diagnostic tests tailored to the needs of chemistry students in the region.

Statements and Declarations

Conflict of Interest: The author declares that there are no competing interests.

Funding Information: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Ethics and Consent to Participate: Participation in this study was voluntary. Data were coded and stored separately from students' personal identification to maintain confidentiality during collection and analysis. There were no anticipated risks to participants, and participation was not associated with academic grades. No compensation was provided, and participants were informed of their right to withdraw at any time.

Data Availability: Data sharing is not applicable to this article as no new datasets were generated or analyzed during the current study beyond the qualitative transcripts presented.

Authors' Contributions: The author was responsible for data collection, analysis, and the reporting of results.

Acknowledgements

The author is profoundly grateful to the students who volunteered their time to participate in this study and extends sincere thanks to the Chemistry Department at the University of Benghazi (UOB), Al-Marj campus, for their support.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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