Research in Science Education (2021) 51:1247–1267
https://doi.org/10.1007/s11165-019-09906-9

Analysis of Articles in *The American Biology Teacher* for Essential Features of Inquiry Representation

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Published online: 24 December 2019

Abstract
Most studies on inquiry have focused on student outcomes, teachers' conceptions of inquiry, implementation of inquiry in science classrooms, and inquiry coverage in science textbooks. Little is known about the nature of inquiry representation in science practitioner journals that serve as sources of inquiry science activities for many science teachers, science teacher educators, college instructors, and informal science practitioners. Therefore, this study examined the nature of inquiry representation in the articles that were published in *The American Biology Teacher* from 1998 to 2015. The study also sought to find out if there was a difference in inquiry representation between the articles that were written by teachers and college instructors. The nature of inquiry representation in the articles was determined by establishing the extent to which six essential features of inquiry—*question*, *evidence*, *analysis*, *explain*, *connect*, and *communicate*—were addressed in the articles. Results showed that most essential features of inquiry were adequately represented in the articles analyzed. However, most science activities did not have investigative questions to guide the inquiry process. We also found a significant difference in inquiry representation between the articles written by biology teachers and college instructors. Teachers addressed more essential features of inquiry in the articles than college instructors. On the other hand, there was no significant difference in the degree of student-directedness inquiry in the articles written by the teachers and college instructors. Overall, there was more partial inquiry than full inquiry representation in the articles analyzed. Implications of the findings and recommendations are discussed.

Keywords Inquiry-based learning · Practitioner journals · Teacher education · Representation of inquiry features

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Introduction

The science education community emphasizes the use of inquiry-based instruction in science classrooms, in order to promote scientific literacy among students (Capps et al. 2012; McLaughlin and MacFadden 2014; Plummer and Ozcelik 2015; van Uum et al. 2016; Srisawasdi and Panjaburee 2015). As such, several countries such as England (Millar and Osborne 1998), Australia (Goodrun et al. 2000), Lebanon (National Center for Educational Research and Development 1997), and Israel (Tomorrow 98 1992) have science curricula that are designed for preparing future scientists and educating students to be scientifically literate. Additionally, these nations emphasize inquiry teaching and learning in pursuing the two goals. Similarly, the United States National Science Education Standards (National Research Council [NRC] 1996) and the *New Framework for K-12 Science Education* (NRC 2012) and the Next Generation Science Standards (NGSS) (NGSS Lead States 2013) accentuate inquiry instruction in K-12 science classrooms through science practices.

Since the concept of inquiry-based instruction was articulated by Joseph Schwab in the 1960s when he protested the teaching of science as a presentation of scientific facts (Schwab and Brandwein 1962), several descriptions of inquiry have emerged. For example, Bell et al. (2005)described inquiry as “an active learning process in which students answer research questions through data analysis” (p. 31). Additionally, Minstrell and van Zee (2000) state that inquiry is a complex process that encompasses different dimensions, including fostering curiosity and providing teaching strategies for motivating students to learn. The National Research Council [NRC] (2000) states that “Inquiry…refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world” (p. 23). Despite these different descriptions of inquiry, there is a consensus in the science education community that inquiry is both a teaching approach (Dunne et al. 2013; Isabelle and de Groot 2008) and a learning goal (Capps et al. 2012). As a teaching approach, inquiry involves students learning how to ask questions, proposing explanations, testing those explanations against current scientific knowledge, and sharing their ideas with peers and teachers (Schneider 2013; NRC 1996), as well as learning to question their own observations and those made by others (Morrison 2013) and dealing with frustrations of experimental errors, missing data, and uncontrolled variables (Lakin and Wallace 2015). Inquiry learning goals include fostering skills to do inquiry activities and understanding the foundations of scientific inquiry among learners (McLaughlin and MacFadden 2014).

According to NRC (2000), inquiry instruction has five essential features: (1) Learners are engaged in scientifically oriented questions (question); (2) learners collect evidence to answer investigative questions (evidence); (3) learners formulate explanations from evidence to address scientifically oriented questions (explain); (4) learners evaluate their explanations in light of scientific knowledge (connect); and (5) learners communicate and justify their proposed explanations (communicate). Asay and Orgill (2010) expanded essential feature 2 to learners give priority to evidence (evidence) and learners analyze evidence (analysis). The rationale for modifying essential feature 2 was because in inquiry instruction students can answer an investigative question by either collecting and analyzing their own data or through analyzing data that was collected by others. The modification of essential feature 2 resulted into six essential features of inquiry—*question*, *evidence*, *analysis*, *explain*, *connect*, and *communicate*. Each of these essential features of inquiry can occur in varying degrees in science classrooms—student-centered or teacher-centered. The extent to which the features of inquiry are addressed in science instruction or activities leads to the categorization of inquiry as either full or partial inquiry. For example, NRC (2000) says

> "when a teacher or textbook does not engage students with a question but begins by assigning an experiment, an essential element of inquiry is missing and the inquiry is partial…If all (of the essential features) of classroom inquiry are present, the inquiry is said to be full" (p. 28).

Therefore, in this paper, science activities that had all six essential features of inquiry were considered as full inquiry activities, while those that had less than six inquiry features were classified as partial inquiry activities.

The emphasis of inquiry-based instruction in science classrooms has led researchers to examine inquiry implementation in science classrooms (Lotter et al. 2013), teachers' conceptions of inquiry (Breslyn and McGinnis 2012; Ireland et al. 2012; Isabelle and de Groot 2008), teachers' pedagogical orientations toward inquiry (Meis Friedrichsen and Dana 2005), student outcomes regarding science learning and student attitudes for inquiry-based instruction (Sesen and Tarhan 2013), and coverage of inquiry levels, skills, and inquiry features in science instructional materials (Mumba et al. 2007a, b; Aldahmash et al. 2016). In general, these studies demonstrate that inquiry instruction can foster a deeper student understanding of both the science content knowledge and the science process skills (Blanchard et al. 2010) among learners. Additionally, inquiry can positively influence students' attitudes toward science (Sadeh and Zion 2012; Sesen and Tarhan 2013). Students, who receive inquiry instruction, develop a personal motivation and sense of autonomy in learning science (Saunders-Stewart et al. 2012), as well as an understanding of what it means to "do science" and to participate in a scientific community. Studies also report that teachers' conceptions of inquiry and their inquiry implementation are inconsistent with the visions of inquiry as prescribed by the science education reforms (Capps et al. 2012; Kang et al. 2008; Morrison 2013). For example, Kang et al. (2008) reported that science teachers did not have a good understanding of full and partial inquiry instruction. Most teachers reported using partial inquiry science activities, neglecting other inquiry skills. Roehrig and Luft (2004) listed the understanding of the nature of science and scientific inquiry, content knowledge, and pedagogical knowledge as constraints beginning teachers face when implementing inquiry. Additionally, instructional materials such as science textbooks and laboratory manuals influence both teachers' knowledge of inquiry-based instruction and the way in which they implement it in their classrooms (Capps et al. 2016; Schneider 2013). As such, researchers have analyzed science instructional materials that teachers use in their classrooms for inquiry levels and skills representation (Campanile et al. 2015; Mumba et al. 2007a, b). For example, in the analysis of seven high school biology textbooks, Campanile et al. (2015) examined the explicit and implicit features of inquiry. Results showed 128 instances of scientific inquiry, with only three explicit references to scientific inquiry, and that led researchers to recommend further research on how teachers use instances of scientific inquiry in textbooks and other materials. Similarly, Mumba et al (2007a, b) reported low levels of inquiry in science syllabi and textbooks. Chiappetta and Fillman (2007) found that the nature of science received a better representation in the new US biology textbooks, than in the biology textbooks they had analyzed in 1998. In another study, Park et al. (2009) compared the US and Korean earth science curriculum for inquiry levels and skills coverage. The analysis revealed that the Korean textbooks had more inquiry skills coverage than the US textbooks. Dunne et al. (2013) also reported that the Irish elementary school science textbooks had representations of inquiry and the potential to promote inquiry skills among students. Recently, Aldahmash et al. (2016) examined Saudi Arabian middle school science textbooks for essential features of inquiry coverage and found that most science activities engaged students in teacher-directed data collection and explanation formulation. However, very few science activities had investigative questions, and students were rarely engaged in testing their explanations against scientific knowledge.

Although several studies have been done on inquiry, most of them have focused on student learning, teachers' conceptions of inquiry, the implementation of inquiry instruction in science classrooms, and inquiry coverage in science textbooks, laboratory manuals, syllabuses, and examinations. Little is known about the nature of inquiry representation in the science practitioner journals accessible to teachers and researchers. Apart from the study by Asay and Orgill (2010), which examined inquiry practices in *The Science Teacher*, we did not find any studies which reported inquiry representation in science practitioner journals. As such, there is a dearth of research on the nature of inquiry representation in science activities that are published in science practitioner journals. Yet, science practitioner journals continue to serve as sources of peer-reviewed inquiry activities for many science teachers, science teacher educators, and college instructors. Science teachers and science teacher educators disseminate or share their inquiry science teaching ideas and activities with peers in science practitioner journals. As such, the articles published in science practitioner journals might provide a window into the type of inquiry instruction the authors tend to emphasize. This might also give us an idea of how the authors teach science by inquiry in their classrooms.

Although Google searches yield inquiry activities, most of those activities are not peer-reviewed or tested in science classrooms. Some activities on internet have misconceptions which can lead to student learning incorrect scientific concepts. Science activities that are published in science practitioner journals are peer-reviewed for both innovative way of teaching science and presentation of correct scientific concepts.

In view of the above, more attention to inquiry representation in science practitioner journals that are accessible to science teachers, science teacher educators, and researchers is warranted as it may contribute to better inquiry science teaching and learning in schools and science teacher education. This study, therefore, goes beyond previous studies on inquiry instructional materials by examining the articles in a single science discipline practitioner journal for inquiry representation. We examined the nature of inquiry representation in the articles that were published in *The American Biology Teacher* (*ABT*) from 1998 to 2015. The study also sought to find out if there was a difference in inquiry representation in the articles that were written by biology and life science teachers and college biology instructors. This second purpose of the study was based on our assumption that biology and life science teachers and college biology instructors serve different age groups of students, and they are likely to emphasize different essential features of inquiry in their instruction. In this paper, college instructors are those who teach in postsecondary institutions (universities and colleges).

Although inquiry has been talked about for many years, we decided to analyze the articles that were published in the *ABT* from 1998 to 2015 for the following reasons: (a) the US National Science Education Standards (NSES) (1996) that emphasized inquiry were published in 1996 and fully implemented in 1998 and (b) the addendum to NSES (*Inquiry and the National Science Education Standards: A Guide for Teaching and Learning*) *was* published in 2000. Our analysis began with 1998, as earlier articles would have been submitted either prior to publication of the 1996 Standards or at the very beginning of their use in classroom instruction.

The nature of inquiry representation was determined by establishing the extent to which these six essential features of inquiry, *question*, *evidence*, *analysis*, *explain*, *connect*, and *communicate*, were covered in the science activities that were published in the *ABT* during the 18-year period. The *ABT* is published by the US National Association of Biology Teachers (NABT), the world's largest professional organization for biologists and biology educators. We chose to analyze the articles in the *ABT* for four main reasons: (1) It is the only major biology education practitioner journal in the world; (2) its articles are directed toward biology and life science teachers, science teacher educators, and university and college biology instructors in the USA and beyond; (3) its articles are written by biologists and practitioners–biology teachers, science teacher educators, and university and college biology instructors in the USA and other countries (e.g., Germany—Asshoff and Roth 2011; Turkey—Aydin 2015; South Africa—De Beer and Whitlock 2009); and (4) there is a large number of users of the *ABT* around the world. For example, the *ABT* editor, McComas (2018) wrote that there were

> "more than 100,000 users from July 2017 to June 2018 (up 23% from the previous year). Even our global reach has expanded with interest in the journal coming from countries such as India, Australia, Indonesia, China, Brazil, and Germany, and increasing numbers of article submissions now coming from overseas" (p. 555).

The *ABT* editorial office also said during the same period the users were in 205 countries, 54% of them were in the USA and 46% were outside the USA. The readership record showed 236,088 downloads of the articles in the *ABT* by users outside and inside the USA between July 2017 and June 2018. Additionally, the *ABT* editorial board states that the goal of the journal is "to support the teaching of K-16 biology and life science." The *ABT* journal

> "solicits and feature articles relating to the content of biology…, biology teaching strategies appropriate to the classroom, laboratory and field sites, trends in biology teaching, and those that offer assistance in the professional development of biology and life science teachers".

As such, we believed that the articles in the *ABT* would give a view of the nature of inquiry representation biology and life science teachers, teacher educators, biologists, and university and college instructors are presenting to their peers and teacher professional development providers. We also believe that the analysis of the *ABT* articles for inquiry representation is not only desirable to US science educators but also to science educators elsewhere who use the *ABT* as a resource for inquiry activities or plan to implement inquiry instruction in science teacher education, schools, colleges, and in informal science learning programs. As such, we anticipated that the findings in this study would be of significance to biology and life science teachers, science teacher educators, curriculum development experts, informal science instructors, and teacher professional development providers in the USA and other countries. For example, as science teacher educators understand the nature of representation of the essential features of inquiry in the *ABT* articles, they can design inquiry activities in their biology methods courses or professional development programs to enable biology and life science teachers to learn how to implement the essential features of inquiry that are not addressed in the articles.

Our analysis of the articles for inquiry representation in the *ABT* was not aimed at judging the *quality* of the journal or individual authors or the articles themselves. Instead, the goal was to report on the essential features of inquiry that were more salient to the biology and life science teachers, biologists, teacher educators, and college biology instructors who chose to publish their biology activities in the *ABT*.

Research Questions

1. What essential features of inquiry were emphasized in biology articles that were published in *The American Biology Teacher* from 1998 to 2015?

2. What is the degree of student-directedness of the essential features of inquiry in the *ABT* over the 18-year period?

3. Is there a significant difference in the inquiry features representation between the *ABT* articles written by teachers and college instructors?

Methodology

Data Sources

A total of 1281 feature articles were published in *The American Biology Teacher* from 1998 to 2015. After applying both the inclusion and exclusion criteria described below (see Tables 1 and 2), 653 articles met the inclusion criteria. The selected articles in each year were listed and assigned a number. Then, 60% of the articles were randomly selected from each year for analysis using the assigned numbers, which resulted into a total of 394 articles analyzed. It was assumed that 60% of the articles would give us more than half of the articles to analyze for inquiry representation in the *ABT*.

We started analyzing the articles that were published in 1998, as earlier articles may have been submitted either prior to publication or implementation of the US *National Science Education Standards* (NRC 1996). We were also interested to see whether there was any

Table 1 Inclusion criteria (adapted from Asay and Orgill 2010)

Criterion	Criterion description	Example of article that meets criterion
Described classroom activity or activities	Detailed description of what actually happened in a science classroom; not an untried possibility or concept	Non-science majors in a college biology course completed a project in which they examined the microbial contamination of chicken wings (Deutch 2001).
Focused on learning science content	Main purpose of the activity was learning science content; could include integration of other content areas if science was the focus	The activity focuses on the relationship between genotypes and phenotypes using a PRC-based lab (Briju and Wyatt 2015).
Part of curriculum	Classroom activities as part of the school day; all students participate, not just a select few; could include after school activities or homework in addition to classroom activities	Describes a project that teaches students about different species and biodiversity through the examination of the types of amphibians and reptiles on school property (Tomasek et al. 2005).
Student activities	Describes what students do rather than an experience of the teacher as the learner	Provides a lesson plan and handouts with student instructions. The activity examines the freeze tolerance in the Goldenrod Gall Fly (Sandro and 2006).

Table 2 Exclusion criteria (adapted from Asay and Orgill 2010)

Criterion	Criterion description	Example of article that meets criterion
Book review	Reviews and/or describes books related to science topics or science education.	A review of *Cancer Virus: The Story of Epstein-Barr* book (Cowles 2015)
Facilities or equipment design	Gives background information or instructions for designing and/or constructing equipment or facilities.	Explains how to create a light sensor for aquatic habitats (Tatina 1998).
How to do	Gives instructions for a teacher, such as how to do a particular lab or demonstration.	Provides directions for an animal behavior experiment that addresses foraging behavior in guppies (Rop 2001).
Literature review	Describes literature related to a particular topic.	Examines the practitioner literature focusing on lab-based instruction in biology classrooms in the "The American Biology Teacher" (Puttick et al. 2015).
Opinions or philosophies	Promotes a point of view, argues for a cause, or makes a philosophical stand.	An editorial discussing possible viewpoints as to why biology is considered a "tough" course (Leonard and Merill 2009)
Professional development	Describes teacher learning opportunities or programs.	Discusses professional development programs for biology graduate students, which emphasizes pedagogy (Lockwood et al. 2014).
Research	Describes and/or discusses research about science education: a teacher's research, a professional's research, or a teacher's experience as a participant in research.	Focuses on results from the first implementation of a course for preservice elementary teachers centered on life science disciplinary knowledge and instructional models (Forbes et al. 2015).
Science content	Provides information on scientific principles, current research, or background information meant to increase teachers' knowledge.	Discussion of findings regarding bacterial genomes in light of the sequencing of the human genome (Flannery 2001)
Teaching strategies	Describes strategies that teachers can use to promote learning, such as grouping, types of lectures, contracts, inclusive practices, assessment, questioning, etc.	Discusses a model for teaching scientific writing, which uses critical thinking and research (Krest 1999).

difference in the inquiry representation in the articles that were published before and after the publication of *Inquiry and National Science Education Standards: A Guide for Teaching and Learning* (NRC 2000), the addendum to the 1996 National Science Education Standards which provides guidelines on inquiry science teaching and learning.

Article Selection Criteria

The articles were selected using the inclusion and exclusion procedures developed by Asay and Orgill (2010) (see Tables 1 and 2). The inclusion selection criteria were (1) articles described classroom activities—a detailed description of what actually happened in a science lesson, roles of the teacher and students are provided, and not an untried possibility or concept; (2) articles focused on learning science content and process skills; and (3) articles were part of the curriculum; and (4) student activities.

The articles were excluded from the analysis if they described a book review; facilities or equipment design; how to do a lab or demo (an article that only provide instructions for the teacher, such as how to do a particular lab or demonstration); literature review;

opinions or philosophies; professional development; research; science content; and teaching strategies. The criteria also excluded articles that did not provide the role of the students.

Analysis Framework

The nature of inquiry representation in the feature articles was determined using the modified essential features of inquiry and variations framework (Asay and Orgill 2010) (see Table 3). The original framework (NRC 2000) has five essential features of inquiry: (1) learner engages in scientifically oriented questions, (2) learner gives priority to evidence in responding to questions, (3) learner formulates explanations from evidence,

Table 3 Modified essential features of inquiry table (Asay and Orgill 2010)

Essential features	Variations			
	1	2	3	4
1. Learner engages in scientifically oriented questions (question).	Learner poses a scientifically oriented question.	Learner selects among scientifically oriented questions and poses new scientifically oriented questions.	Learner sharpens or clarifies scientifically oriented questions provided by teacher, materials, or other source.	Learner engages in scientifically oriented question provided by teacher, materials, or other source.
2. Learner gives priority to evidence (evidence).	Learner determines what constitutes evidence and collects it.	Learner guided to collect certain data/evidence.	Learner given possible data/evidence.	Learner given data/evidence.
3. Learner analyzes evidence (analysis).	Learner determines how to analyze evidence	Learner guided in analyzing data/evidence	Learner given possible ways to analyze data/evidence	Learner told how to analyze data
4. Learner formulates explanations from evidence (explain).	Learner formulates explanations based on evidence.	Learner guided in process of formulating explanations from evidence.	Learner given possible ways to use evidence to formulate explanations.	Learner told how to use evidence to formulate explanations.
5. Learner connects explanations to scientific knowledge (connect).	Learner independently examines other resources and forms the links to explanations.	Learner directed toward areas and sources of scientific knowledge and students form links to explanations.	Learner given possible connections.	
6. Learner communicates and justifies explanations (communicate).	Learner chooses how to communicate and justify explanations.	Learner coached in development of communication and justification of explanations.	Learner provided with broad guidelines to sharpen communication and justify explanations (or given possible types of communication to use).	Learner given steps and procedures for communication and justification of explanations.
	More ← Amount of learner self-direction → Less Less ← Amount of direction from teacher or material → More			

(4) learner connects explanations to scientific knowledge, and (5) learner communicates and justifies explanations. Asay and Orgill modified feature 2 by splitting it into two parts: *evidence* (2a: the learner gives priority to evidence) and *analysis* (2b: the learner analyzes evidence). The rationale for splitting this essential feature of inquiry was because sometimes students are engaged in inquiry activities in which they are not able to collect data (e.g., data on nuclear chemistry, or solar system). Instead, students analyze data that was collected by scientists who have the appropriate data collection instruments. In this paper, *evidence* and *analysis* are labeled features 2 and 3, respectively.

First, two biology education experts independently read each article and assigned a ranking for each essential feature of inquiry (1, 2, 3, 4, 5, 6) (see Fig. 1). Second, the essential features of inquiry identified in each article were ranked on a variation scale of 1–4, with 1 being the most student-centered and 4 being the most teacher-centered (see Table 3). The essential features of inquiry that were not present were coded as (–) and essential features of inquiry that were not clear were marked (X). Third, the average number of essential features of inquiry per year, the percentage of articles by the number of essential features of inquiry, and the degree of variation of essential features of inquiry (1 and 2 = student-centered; 3 and 4 = teacher-centered) were computed. We also performed independent *t* test to find out if there was a difference in the inquiry features representation between the articles that were written by teachers and college instructors.

Interrater Reliability

Two biology educators independently analyzed the articles for inquiry representation using the procedures described above. Then, the two coders met to compare and discuss their analyses. Differences that emerged in their analyses were resolved through sustained discussions and re-examination of the articles in question for inquiry features. Mean scores were computed where there were still disagreements between the coders. An interrater reliability coefficient was calculated using Cohen's kappa (Cohen 1960) procedure. This coefficient factors in chance agreement and represents a measure of reliability. The percentage agreement between the two raters for inquiry representation in the articles analysis ranged from 84 to 92% with a corresponding range of kappa values from 0.81 to 0.94. These statistics suggest a high degree of agreement between the two raters in categorizing essential features of inquiry in the articles. Values above 75% indicate excellent percentage agreement, while kappa values below 0.4 indicate a poor interrater coefficient (Chiappetta et al. 1991).

Results

Essential Features of Inquiry in the Articles

As shown in Fig. 1, all the articles ($n = 394$) analyzed contained at least one essential feature of inquiry; however, very few articles contained only one. Only one fifth of the articles addressed all six essential features of inquiry, so most of the articles included partial inquiry activities. The NRC (2000) asserts that partial inquiry activities are those that do not engage students in all essential features of inquiry, while full inquiry activities are those that engage students in all essential features of inquiry.

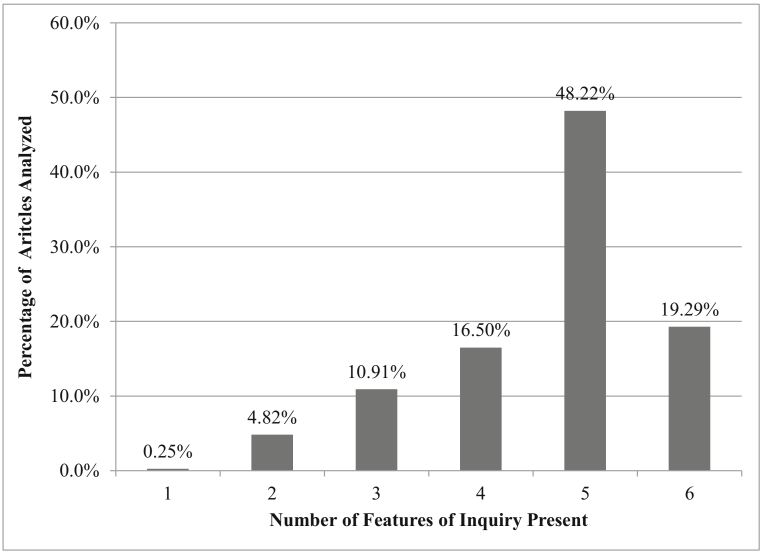

Fig. 1 Percentage of articles by number of features of inquiry present

Average Essential Features of Inquiry per Year

There was an average of 4.64 essential features of inquiry per article over the 18 years we analyzed. As shown in Fig. 2, the lowest average number of features of inquiry per article occurred in 1998, and the highest average number of essential features per article occurred in 1999, 2006, and 2012. Overall, the average number of essential features of inquiry in the

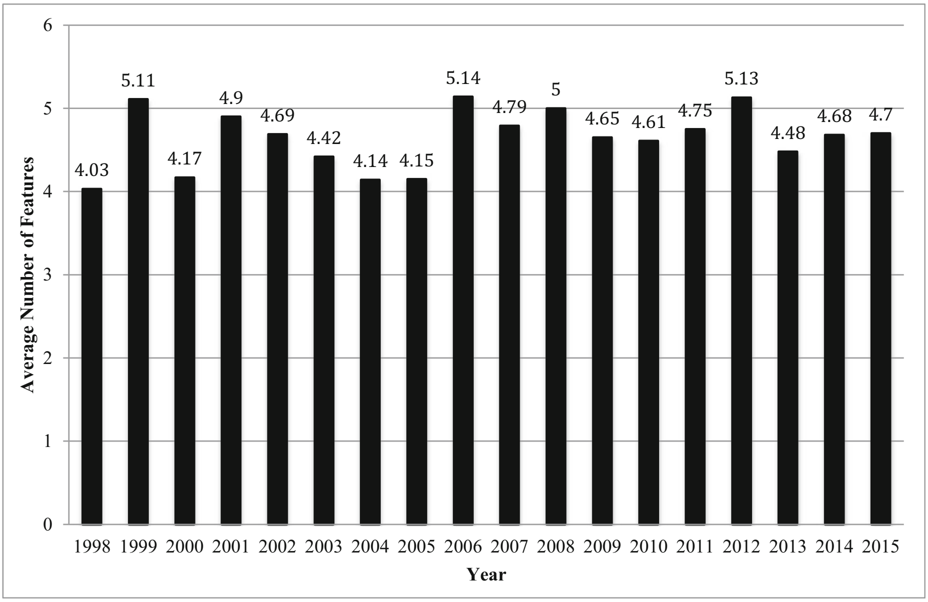

Fig. 2 Average number of essential features in analyzed articles per year ($N = 394$)

articles per year changed very little over the period we analyzed. These results suggest that the degree of partial inquiry in the articles analyzed was almost constant during the 18-year period.

Specific Essential Features of Inquiry

As shown in Fig. 3, five out of six essential features—*evidence*, *explain*, *communicate*, *analysis*, and *connect*—were significantly covered in the articles during the 18-year period. Conversely, only a quarter of the articles had scientifically oriented *questions*. Table 4 shows that most articles did not include an investigative question to drive the inquiry process. Instead, the articles had learning objectives, purpose, goals, problem statements, challenges, and hypotheses as prompts to inquiry investigations. Although these prompts are used to engage students in active learning process, the National Science Education Standards (NRC 2000) clearly states that a scientifically oriented question should drive an inquiry process. Bell et al. (2005) also described inquiry as a process of answering investigative questions through data analysis. About a third of the articles had neither questions nor any other form of prompt to drive the inquiry process (see Table 4). Table 4 also shows there were more student-directed than teacher-directed hypothesis prompts in the articles we analyzed. The other prompts were mostly teacher-directed.

These results suggest that the partial inquiry activities published in the *ABT* mainly provided opportunities for students to develop hypotheses, collect evidence and analyze it, formulate explanations, connect explanations to existing scientific literature, and communicate and justify their explanations to teachers and peers.

Student-Directedness Versus Teacher-Directedness

We analyzed the articles to determine whether the essential features of inquiry in the articles were student-centered or teacher-centered. As indicated in Fig. 4, some inquiry features were more student-centered than others. For example, *evidence* and *communicate* were the most student-centered (rated either at level 1 or 2 on the variation scale of 1–4) essential features of inquiry in the articles analyzed. This means that most activities required students to collect data and communicate and justify their explanations.

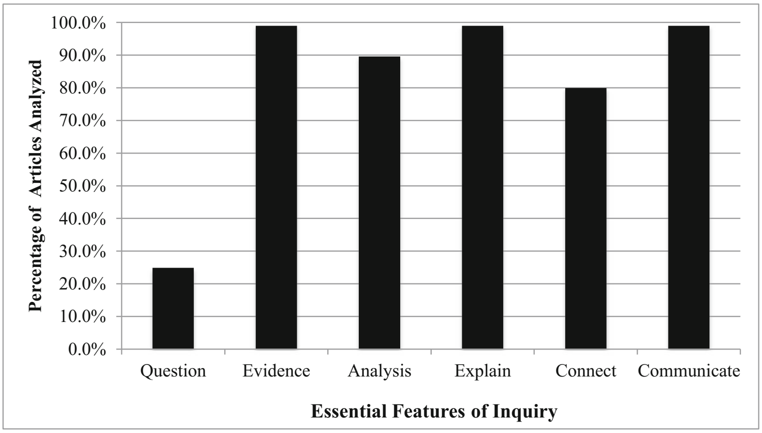

Fig. 3 Essential features of inquiry present in analyzed articles (N = 394)

Table 4 Articles with no scientifically oriented questions

Type of prompt	Number of articles	Percent (%)	Example article
Objective	69 TC—69 SC—0	23.34	Davenport et al. (2015)
Hypothesis	82 TC—20 SC—62	27.71 6.76 20.95	De Beer (2012)
Purpose	30 TC—30 SC—0	10.14	Baker and Jones (2006)
Problem	22 TC—20 SC—2	7.44	Clark and Mathis (2000)
Aim	5 TC—5 SC—0	1.69	Lorbiecke (2012)
Goal	45 TC—45 SC—0	15.20	Krist and Showsh (2007)
Rationale	7 TC—7 SC—0	2.36	Marquard and Steinback 2009)
None	117	39.66	Lanza and Cress (2001)

Note: Articles can have multiple prompt types; therefore, the total exceeds 100%

TC = teacher-centered; *SC* = student-centered

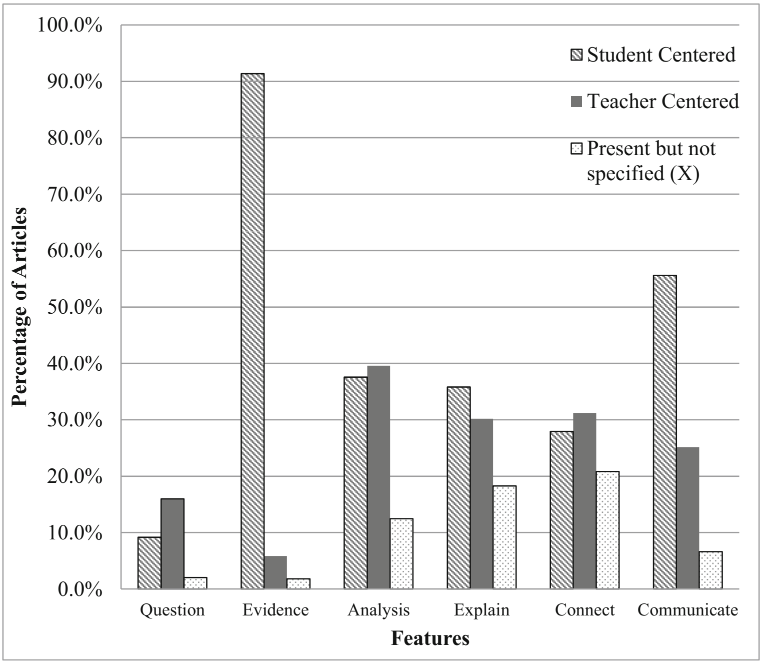

Fig. 4 Percentage of each feature of inquiry present by degree of variation

In the articles with *question* feature, the investigative questions were more teacher-directed than student-directed (see Fig. 4). Although the *analysis* feature received adequate representation in the articles, its degree of variation in science activities was balanced between student-centered and teacher-centered (see Fig. 4). This result suggests that in some articles, students were asked to decide on how to analyze data, and in other activities, students were told by teachers how to analyze data.

The *explain* feature was found in most articles (see Fig. 3) and it was mostly student-directed (see Fig. 4). Students were given opportunities to decide on how to formulate explanations from the evidence they gathered or provided by the teacher. The degree of variation for *connect* feature in the articles was also balanced between teacher-directed and student-directed. The *connect* feature was also coded X "present but not defined" in one quarter of the articles analyzed. This means that one quarter of the articles did not clearly state the role of the student or teacher in connecting explanations to scientific knowledge. Overall, these results suggest that the *question* feature of inquiry was teacher-directed, while *evidence*, *explain*, and *communicate* features were student-directed. The degree of variation of the a*nalysis* and *connect* features of inquiry in the articles was balanced between student- and teacher-directedness (see Fig. 4).

Essential Features by Type of Author

As shown in Table 5, most articles analyzed were written by biology instructors at 4-year colleges, few by biology teachers, community or technical college instructors, and practitioners in informal science settings (e.g., zoos and museums). These subgroups of authors emphasized student collecting evidence and data analysis and communicating their results. On the other hand, only half of the articles written by the practitioners in informal science emphasized student connecting explanations to accepted scientific knowledge. The *question* feature received the least coverage in the articles that were written by community college biology instructors.

Further data analysis was conducted to find out if there was a significant difference in the representation of essential features between the articles that were written by teachers and college instructors. An independent sample t test comparing the mean score of essential features of inquiry in the articles written by college instructors and science teachers revealed a significant difference between the means of the two groups ($t = 2.482$, $p = 0.004$). The mean score of inquiry features in the articles written by science teachers ($M = 5.00$, SD = 0.69) was significantly higher than the mean score of inquiry features in the articles written by college instructors ($M = 4.43$, SD = 1.04). This result suggests that science teachers addressed more essential features of inquiry in the articles than college instructors.

Table 5 Percentage of features by type of author

Type of author	Number of articles	Essential features of inquiry (%)					
		Question	Evidence	Analysis	Explain	Connect	Communicate
Science teachers	51	29.41	98.04	88.24	92.16	84.31	96.08
University instructors	322	24.53	99.07	90.06	83.23	79.50	86.34
Community/technical college instructors	13	7.69	100.00	84.62	84.62	92.31	100.00

Note: Each row is more than 100% because several articles had more than one feature of inquiry

After looking at the extent to which subgroups of authors represented features of inquiry in the articles, we examined the extent to which the activities were student- or teacher-directed. Table 6 compares the degree of student-directedness inquiry in the articles written by science teachers, college instructors, and informal science educators. The *t* test revealed no significant difference in the degree of student-directedness inquiry between science teachers' and college instructors' authored activities ($t = 18.36$, $p = 0.06$). This finding indicates that the degree of student- and teacher-directed inquiry variation was the same in the articles written by teachers and college instructors. The variation of student-directedness inquiry in the articles written by informal science educators was not compared to teachers or college instructors due to a small number of informal science educators who contributed the articles in the period that was analyzed.

Discussion and Implications

The purpose of this study was to examine the nature of inquiry representation in the articles that were published in *ABT* from 1998 to 2015. The study also sought to find out whether there was a significant difference in inquiry representation between the articles that were written by teachers and college instructors. The results show that all the articles analyzed contained at least one essential feature of inquiry. Most essential features of inquiry were adequately represented in the articles. However, most activities did not have investigative questions to guide the inquiry process. This means that in most activities, students were not asked to formulate investigative questions, or no investigative questions were provided to them to answer. Instead, the activities provided learning

Table 6 Degree of student-directedness of essential features of inquiry by type of author

Type of author	Inquiry feature	Degree of student-directedness More → Amount of learner self-direction → Less Less → Amount of direction from teacher or material → More				Could not be determined
		1 (%)	2 (%)	3 (%)	4 (%)	X (%)
Science teachers	Question	3.7	1.5	6.9	85.3	2.6
	Evidence	46.1	48.3	3.2	2.4	0.0
	Analysis	15.3	32.7	23.0	25.1	3.9
	Explain	62.8	28.4	2.7	2.5	3.6
	Connect	20.4	25.6	43.1	N/A	10.9
	Communicate	57.3	26.8	10.1	5.6	0.2
College instructors	Question	2.5	6.4	8.2	79.3	3.6
	Evidence	45.3	43.7	2.2	2.8	6.0
	Analysis	17.4	30.2	25.3	21.8	5.3
	Explain	30.5	59.9	1.9	3.0	4.7
	Connect	18.1	29.9	48.3	N/A	3.9
	Communicate	60.5	23.2	8.7	6.4	1.2
Informal science educators	Question	2.1	3.2	14.5	80.2	0
	Evidence	52.2	40.3	2.6	1.8	3.1
	Analysis	15.7	35.6	30.1	17.6	1.0
	Explain	28.4	61.4	2.9	4.6	2.7
	Connect	17.3	48.6	29.3	N/A	4.8
	Communicate	53.8	30.9	9.5	4.2	1.6

N/A = there is no description corresponding to this variation in the analysis framework (see table) objectives, goals, aims, hypotheses, challenges, and problem as prompts to scientific investigations. We also learned that one third of the articles had neither questions nor any other form of prompt to drive the inquiry process. This finding may be due to the analysis procedure we used or the understanding of inquiry process among the authors of the articles we analyzed. The analysis framework we used was developed using the National Science Education Standards (NRC 1996) and its guidelines for inquiry science teaching (NRC 2000), which assert that investigative question should drive the inquiry process in science classrooms. A *question* is the first essential feature of inquiry listed in both science education reform documents. As such, we did not categorize articles as meeting the criteria for the *question* feature if the prompt in the activity was not provided as an investigative question. We acknowledge that hypotheses, challenges, objectives, aims, and problems are commonly used to guide scientific investigations. However, they are not part of the essential features of inquiry and the definition of inquiry in science education reforms (see NRC 1996; 2000). Another reason for less representation of the *question* feature in the articles analyzed could be due to authors' understanding of inquiry process. Some authors of the articles may not have viewed investigative *question* as an essential feature of inquiry. This claim should be investigated in future studies.

Scientifically oriented questions are essential elements of the inquiry process as they guide investigation and enhance student understanding of the underlying science concepts (Chiappetta and Fillman 2007). Similarly, Osborne et al. (Osborne et al. 2003) assert that the *question* feature of inquiry provides an important link between experiment design and formulation of explanation in inquiry learning process. As such, the *question* feature of inquiry predetermines the purpose of an inquiry activity and the way data should be collected, analyzed, and interpreted.

We also learned that the few scientifically oriented questions that were in the articles were mostly teacher-centered. As such, students were rarely given opportunities to formulate their own investigative questions in the activities we analyzed. Yet, the ability to write scientifically oriented questions is a skill that students need to develop as part of inquiry as a learning goal and teaching approach (Martin-Hansen 2002).

We recommend that science teacher educators should address this problem by designing inquiry activities that allow science teachers to formulate scientifically oriented questions. Similarly, teacher educators should also engage teachers in designing inquiry activities that are driven by investigative questions. We acknowledge that it is very difficult for some teachers to prepare for inquiry activities where students are formulating their own investigative questions. However, there are inquiry instructional models such as problem-based learning and project-based learning that give students opportunities to formulate their own investigative questions.

On the other hand, *evidence*, *analysis*, *explain*, *connect*, and *communication* essential features of inquiry received high representation in the articles analyzed. Students were engaged in evidence gathering and data analysis for them to explain the phenomena under investigation. This finding is consistent with those reported in previous studies. For example, in Saudi Arabia, Aldahmash et al. (2016) reported that the inquiry science activities in the Saudi Arabian middle school science textbooks were characterized by students collecting data. In our study, the *evidence* feature of inquiry was mostly student-directed. We believe that the authors of the activities we analyzed viewed the process of gathering evidence as an integral part of scientific inquiry process. Similarly, Lakin and Wallace (2015) found that teachers who reported implementing higher levels of inquiry asked students to design their own data collection procedures. The *evidence* feature of inquiry enhances students' understanding of the role of empiricism in science and helps to overcome students' misconceptions (Lunetta et al. 2007; Rushton et al. 2011). Likewise, Ireland et al. (2012) state that evidence gathering in the inquiry process is essential because responses to investigative questions, explanations, and justifications should be based on the evidence.

A balanced distribution of teacher-centered and student-centered variation of *analysis* feature in the articles may suggest that some authors of the articles we analyzed viewed students as not skilled enough to analyze data on their own. However, research shows that when students are engaged in analyzing data, they learn more about science concepts under investigation (Ireland et al. 2012). Therefore, one solution to this problem is first to engage students in lower level inquiry activities for them to develop skills required for higher level inquiry process. Another probable reason for this finding is student-centered inquiry requires more instruction time than teacher-centered inquiry. As such, some teachers may implement more teacher-directed inquiry activities in their classrooms. However, it is important that students play a leading role in inquiry instruction for them to develop sound understanding of scientific phenomena and inquiry skills. Student-centered inquiry activities are likely to promote motivation in students, have the potential for encouraging student autonomy, provide student ownership of inquiry activities, and enhance students' interest in science.

We also learned that most activities required students to formulate explanations based on the evidence they had collected or were given to analyze. As such, the *explain* feature was slightly more student-centered than teacher-centered. However, students were not engaged in formulating explanations to answer investigative questions because most articles did not have scientifically oriented questions. Instead, they formulated explanations to answer discussion questions. This finding is in keeping with previous research. Both Aldahmash et al. (2016) and Asay and Orgill (2010) found the *explain* feature in most science activities that did not have investigative questions. When students are engaged in formulating explanations during inquiry activities, they learn more about science concepts and reorganize their knowledge about the phenomena under investigation (Johnson et al. 2007). As such, the *explain* feature of inquiry instruction can also serve as an assessment tool and provide teachers with valuable information for planning instruction to address students' misconceptions on the phenomenon under investigation.

In most articles, students were asked to evaluate their explanations in light of scientific knowledge (*connect*). The variation of *connect* feature of inquiry in the articles was balanced between teacher-directedness and student-directedness. This finding is different from those reported in previous studies. Asay and Orgill (2010) found low representation of the *connect* feature in the articles that were published in *The Science Teacher*. Aldahmash et al. (2016) also reported that the activities in science textbooks did not support students to *connect* their explanations to scientific knowledge. Morrison (2013) observed several inquiry lessons and found that the *connect* feature was rarely addressed by teachers. The *connect* feature is important in inquiry instruction because students learn more about science concepts when they are given opportunities to compare their results to scientifically accepted explanation of the phenomenon under investigation (Martin-Hansen 2002). Teachers can use the *connect* phase of inquiry to address students' misconceptions on the phenomenon they are investigating. The process allows students to compare their understanding of the concept to that of the scientists. If students are not given opportunities to connect their results and explanations with scientific laws, theories, and concepts, they are likely to maintain their misconceptions about the phenomenon under investigation. Therefore, we suggest that science teachers and teacher educators should encourage students to test their explanations against the accepted scientific knowledge.

Most activities required students to communicate and justify their explanations. Very few articles provided students with specific guidelines on how to communicate and justify their explanations. As such, the *communicate* feature was mostly student-centered. In some articles, students were required to present their data to peers in class. Communication and justification are integral elements of inquiry-based instruction and increase student learning (Lakin and Wallace 2015; NRC 1996). The *communicate* feature provides an opportunity for students to examine their own scientific ideas and possibly change to accepted concepts. Both peer and teacher feedbacks are important in communication process. Likewise, scientists learn more from their peers through feedback on the work they disseminate to the scientific community. In our study, the authors of the articles viewed communication as a significant element in the scientific inquiry process.

The results also show a statistically significant difference in the inquiry representation between the articles written by the biology teachers and college biology instructors. The biology teachers addressed more essential features of inquiry than college instructors. For example, the *question* feature received more coverage in the articles that were written by the biology teachers than those written by community college biology instructors. Although there are differences between inquiry instruction in secondary school biology classrooms and college biology laboratories, this finding makes a significant contribution to literature on inquiry science instruction. For example, this is the first study to report the difference between the biology teachers' and college instructors' representation of inquiry in instructional materials. Previous studies only reported the differences in inquiry representation among teachers of different science disciplines. For example, Breslyn and McGinnis (2012) found that biology, chemistry, earth science, and physics teachers held different conceptions of inquiry and enacted inquiry instruction differently. Thus, we can also conclude that the authors' representation of inquiry in the *ABT* articles reflected their conceptions of inquiry and the way they implement inquiry biology instruction in their classrooms.

Although there are some limitations to this study, the findings have implications for teacher education and inquiry instruction in science classrooms. For example, the findings in this study suggest that teacher educators should explicitly teach teachers how to write or ask scientifically oriented questions and other features of inquiry. Such training may result into teachers developing and implementing full inquiry activities in their science classrooms. We also believe that the explicit analysis of science activities for inquiry representation in science teaching methods courses can be utilized. On the other hand, high representation of most essential features of inquiry in the articles we analyzed is the starting point for integration of full inquiry instruction in science classrooms. It is vital to integrate the essential features of inquiry in a manner that would help students use the design skills as knowledge generation and knowledge application contexts and tools. This implies that science activities should engage students in all the essential features of inquiry, and they should therefore be addressed adequately in science curriculum materials. However, this was not the case in all the articles we analyzed. As such, understanding which and to what extent the essential features of inquiry are covered in science curriculum materials is imperative for effective integration of inquiry instruction in science classrooms. For scientific inquiry to serve as an anchoring context for science learning, instructional materials should emphasize all six features of inquiry. If students can formulate investigative questions, specify data collection and analysis procedures, explain the results, connect explanations to accepted scientific knowledge, and justify their explanations, then teachers would be assured that students are developing scientific inquiry skills and content knowledge inherent in the curriculum. Therefore, these findings should communicate to science teachers and teacher educators about the importance of engaging students in all inquiry skills which they can articulate well, and consequently engage in full inquiry process. If students are only exposed to partial inquiry process, they may not learn the scientific inquiry process emphasized by the science education community and in science education reforms.

This study only examined inquiry representation in one science practitioner journal that serves biology and life science teachers, teacher educators, and college biology instructors. To get a holistic picture of inquiry representation in science practitioner journals that are accessible to science teachers and teacher educators, other science practitioner journals should be analyzed.

In addition, we propose that it would be vital to investigate which essential features of inquiry are covered across the grade levels. Such data can be helpful in assessing how inquiry activities should be structured based on when specific inquiry skills would be appropriately emphasized. Of critical importance too, is another study on how student learning would be enhanced when taught how to develop their own investigative questions and other essential features of inquiry as they move across grade levels. Therefore, our research team has already started analyzing other science practitioner journals, that serve elementary, middle, and high school science teachers, for inquiry representation.

Conclusions

Although most essential features of inquiry were adequately represented in the articles analyzed, there was more partial inquiry than full inquiry representation in the 18-year period we considered. Most articles did not have scientific questions to guide students' investigations. The priority was on students gathering evidence, analyzing data, formulating explanations, connecting explanations to scientific knowledge, and communicating results to peers and teachers. One third of the articles had neither questions nor any other form of prompt to drive the inquiry process. The lack of scientifically oriented questions in most articles poses a challenge for the implementation of full inquiry in biology classrooms, especially for teachers and teacher educators who use the *ABT* biology activities. The findings in this study suggest that teachers need more opportunities to develop investigative questions. The degree of variation for *evidence*, *communication*, and *explain* features was student-directed, while *analysis* and *connect* essential features of inquiry had a balanced variation between teacher-centered and student-centered. The *question* feature of inquiry was mostly teacher-directed. The significant difference in inquiry representation between the articles written by biology teachers and college instructors suggests that the former addressed more inquiry features than the latter. Although there were more partial than full inquiry activities in the articles, the *ABT* demonstrated its commitment "to support the teaching of K-16 biology and life science by disseminating activities that engage students in inquiry and active learning process."

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