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The development of an instrument for assessing students' perceptions of biology teachers' instructional use of diagrams

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Abstract

Science teaching involves using scientific diagrams to explain important concepts, to provide visual images, or to motivate students. However, teachers often wonder if their use of diagrams is effective in helping students learn science. This study aimed to help science teachers evaluate how students perceive their use of diagrams during instruction. Subsequently, we adapted an instrument to measure students' perceptions of science teachers' instructional use of diagrams based on Tuan et al.'s (2000) Student Perceptions of Teachers' Knowledge (SPOTK) questionnaire. The adapted instrument initially had four categories – teacher's instructional practice in using diagrams; teacher's use of multiple forms of scientific representations; teacher's use of diagrams in assessment practices; and students' understanding of and competence in using scientific diagrams. The instrument was administered to 215 Australian high school biology students in Years 9-10. Following factor analysis, 20 items remained in the final instrument and three scales were extracted – Instruction with Diagrams, Assessment with Diagrams, and Students' Diagrammatic Competency. The reliability of the total instrument Students' Perceptions of Teachers' Use of Biology Diagrams was 0.91 and the reliability of each category ranged from 0.65 to 0.90. This instrument is specifically related to the diagrammatic usage in biology lessons and, hopefully, with further research can be generalised to other science lessons. Future research will investigate the relationship between teachers' instruction with diagrams and students' understanding of them.

Introduction

Diagrams are powerful in illustrating various natural phenomena. They are an essential tool to understand and convey scientific information in science journals, newspapers, or magazines (Cheng & Gilbert, 2009). Especially in biology, diagrams have a prominent role in communicating and teaching important concepts. Studies have found that there are numerous photographs, diagrams and naturalistic drawings on almost every page of biology textbooks (Pozzer & Roth, 2003; Roth, Bowen, & McGinn, 1999). Many science teachers report that they frequently use diagrams in their instruction and researchers have found that diagrams can greatly help build students' understanding in various ways (Ainsworth, 2006). Well-illustrated diagrams can help students to visualize complex biological or physical phenomena which are often hidden from their direct observation or experiences (Buckley, 2000). Diagrams reduce the amount of cognitive effort to solve equivalent science problems (Ainsworth, 2006) and they can limit the ambiguity of textual explanation of science concepts (Stenning, Cox, & Oberlander, 1995).

While diagrams are beneficial and widely used in science classrooms, students often encounter difficulties in interpreting diagrams or finding the relations between the diagrams and the concepts they represent. Novick (2006) and Roth and his colleagues (1999) noted that diagrams usually delete less important (or less relevant) information to the main concept and this may contribute to students' difficulty. A different level of abstraction in diagrams is among many factors affecting students' understanding. According to Hegarty, Carpenter, and Just (1991), scientific diagrams can be classified into three categories: iconic, schematic, and charts and graphs. An iconic diagram refers to accurate depiction of concrete objects. Because iconic diagrams look like what they represent, they are effective in helping students recognize different kinds of physical systems that are not available to visual inspection (Hegarty, et al., 1991). Schematic diagrams, on the other hand, are abstract diagrams that simplify complicated situations by providing a concise depiction of their structures and functions (Lynch, 1990). Charts and graphs depict a set of related, typically quantitative data and numerical meanings based on interpreting independent variables.

Different diagrams have their own advantages and limitations in guiding learning, so teachers need to critically evaluate their use of diagrams by asking questions such as: How do my students perceive diagrams in relation to the science concepts I've been trying to teach? How do the diagrams I've been using in class really work for my students' benefit? How competent do my students feel in interpreting and drawing diagrams for science learning?

In order to help teachers to evaluate their use of diagrams during instruction, we developed an instrument to identify students' perceptions regarding instructional use of diagrams in their biology class. Since students have encountered various learning environments during their time at school and are in a good position to form accurate impressions about classroom (Fraser, 1998), we believed that it would be worthwhile to develop an instrument exploring students' perceptions.

Teachers may use the instrument results to evaluate and reorganize their use of scientific diagrams in class to improve their teaching practices.

Many studies have suggested the centrality of teacher's role in creating a learning environment that promotes students' cognitive and affective learning achievements within the educational processes. We referred to Tuan et al.'s (2000) instrument, which has categories related to instruction, representation, subject matter knowledge, and knowledge of how to assess students' understanding. Subsequently we intended to design an instrument to determine the four dimensions of teachers' instructional use of diagrams. The four original scales included Instructional perspectives focused on the generic teaching practice with diagrams; Representational perspective aimed at the representational features of diagrammatic teaching; Assessment perspective discussed the possibility of diagrams to be utilized in evaluating students' learning; and Competence perspective addressed the importance of having essential techniques and skills for learners to interpret diagrams.

Methods

The development of the instrument for assessing students' perceptions of teachers' instructional usage of diagrams followed several stages: The initial efforts were spent on identifying and defining the salient nature and the characteristics of teaching approaches in the multiple representational learning environments. By conducting an extensive review of research on the functional value of multiple representations for science teaching and teachers' pedagogical content knowledge, we identified key components in diagrammatic teaching and improved the content validity of the instrument.

The second stage was to write the items for each scale. Items from the previously validated instruments SPOTK were examined and adapted if possible. Particular interest was to determine if the scales reported by previous studies will hold up when the focus is placed on teaching biology with diagrams. A five-level Likert scale was adopted in the response format, namely strongly disagree, disagree, not sure, agree, and strongly agree. Once the items within each scale had been written up, several science education researchers and three experienced biology teachers' opinions were sought to assess comprehensibility, suitability, and accuracy of items under each scale. After the discussion and review process, we removed some inappropriate items and added some new ones, then decided on the instrument of 24 items in four categories.

Subsequently the questionnaires were administered to 215 students in Years 9 and 10 from four teachers' classes in one senior high school in Western Australia. Students' participation was on a voluntary basis. After collecting the data, we ran descriptive statistics, exploratory factor analysis and internal consistency reliability analysis using the Statistical Package for Social Scientists (SPSS).

Results and Discussion

Factor analysis

Conducting the factor analysis using a varimax rotation showed that the four original scales in the questionnaire were not supported. After removing four items that did not fit into a single scale and repeating the factor analysis using a varimax rotation, we identified three distinct scales in the instrument, namely, Instruction with Diagrams, Assessment with Diagrams and Students' Diagrammatic Competency (see Table 1).

The omitted four items were loaded on two scales. For example, one item from the original scale Assessment with Diagrams, "My teacher's tests evaluate my understanding of diagrams of a biology topic", has loaded on both Instruction with Diagrams (0.43) and Assessment with Diagrams (0.55). However, based on the researchers' observations of diagrammatic usage in teaching activities, we realized that diagrams were often included in teachers' handouts and students' workbooks that have both of the instruction and assessment features. Consequently, the authors decided to have this item removed, as its ambiguity in the way of questioning may prevent students from interpreting the accurate intention of what has been evaluating and thus may further affect the entire reliability of the instrument. For the same reason, the other three items have been deleted from the original instrument.

The scale 'Instruction with Diagrams' explores how scientific diagrams are employed as an instructional tool in facilitating students' learning of biology concepts. Ten items from the former Instructional category and Representational category were grouped into this scale; these are items 1 through10. The factor loadings of 'Instruction with Diagrams' ranged from 0.46 to 0.74. The Cronbach alpha value for this scale was 0.90, indicating that items were a reliable measure of the categories of teachers' instructional use of diagrams (see Table 2). Examples of items from this scale are: "My teacher uses a variety of diagrams when we study different biology topics" (item 3) and "My teacher uses diagrams that are familiar to me to explain biology concepts" (item 4).

The scale 'Assessment with Diagrams' refers to how the diagrams were used to evaluate students' learning of biology concepts and contains five items, 11, 12, 13, 14, and 15. The Cronbach alpha value is relatively high, 0.87. Factor loadings of 'Assessment with Diagrams' ranged from 0.60 to 0.71. Examples of items in this category include: "My teacher's questions evaluate my understanding of diagrams while the teaching is in progress" (item 12); "My teacher's tests evaluate my understanding of diagram of a biology topic" (item 11).

The scale 'Students' Diagrammatic Competency' deals with students' perceptions on prerequisite skills and abilities to interpret the biological diagrams. The five items forming this scale are item 16 through 20 with a reliability value of 0.65, the lowest of the three scales (see Table 2). Factor loading of 'Students' Diagrammatic Competency' ranged from 0.50 to 0.67. Examples of items include: "Diagrams have a role to play in bridging the gap between what I already know and the biology knowledge that I am going to learn" (item 20); and "When I can explain a biology concept with different types of diagrams, I feel more confident about my learning" (item 18).

Table 1. Factor loadings, eigenvalues, and percentage of variance for the Students' Perceptions on Teachers' Use of Biology Diagrams Instrument in this study (n = 215)

	Factor loading		
Item No	Instructional	Assessment	Competence
1	0.61		
2	0.50		
3	0.74		
4	0.61		
5	0.69		
6	0.72		
7	0.66		
8	0.46		
9	0.55		
10	0.64		
11		0.71	
12		0.65	
13		0.63	
14		0.64	
15		0.60	
16			0.67
17			0.63
18			0.62
19			0.51
20			0.50
Eigenvalue	9.05	1.50	1.29
% Variance	39.36	6.54	5.60
Cumulative % variance	39.36	45.9	51.5

Factor loadings less than 0.4 have been omitted from the table. Principal axis factoring with varimax rotation and Kaiser Normalization was used.

Table 2. Cronbach alpha reliability values and descriptive statistics of the three scales of *Students' Perceptions on Teachers' Use of Biology Diagrams*.

			Teacher S			Teacher D			Teacher C			Teacher B		
Scale	N of items	Cronbach's Alpha	*N* of students	M	SD	*N* of students	M	SD	*N* of students	M	SD	*N* of students	M	SD
Instruction	10	0.90	37	3.10	1.02	31	4.21	0.83	106	3.32	1.1	41	3.8	0.78
Assessment	5	0.87	37	3.2	1.05	31	4.14	0.81	106	3.25	1.04	41	3.74	0.75
Competence	5	0.65	37	3.33	0.90	31	3.86	0.87	106	3.49	0.83	41	3.57	0.83

Validity of the instrument

The validity of the instrument was confirmed in terms of its content and construct validity. Content validity refers to the degree that the instrument covers the content that it is supposed to measure (Yaghmale, 2009). In this regard, the content validity was based on observations of teaching and discussions with experienced biology teachers during the process of designing the instrument. The researchers spent several consecutive school semesters observing biology teachers' daily teaching and these observations provided the first-hand insight into knowing individual teacher's teaching practice and students' behaviour. Moreover, reference was made to research on teachers' pedagogical content knowledge and features of visual teaching and learning.

The items in the instrument were cross-checked by several experienced science teachers and science educators to ascertain the content of the scales. According to their feedback, the revision of items has been undertaken in many aspects: 1) removing the negatively worded statements to eliminate unnecessary confusion (Barnette, 2000); 2) simplifying items that were too complicated to represent the succinct constructs in the scales. 3) rephrasing and making sentences much clear and concise. Taken together, the major wordings adaptations were made to ensure the statements are less academic and more comprehensible to secondary students.

Findings from content validity contributed to supporting the construct validity of the instrument. According to Arthur, Day and Woehr (2008), construct validity pertains to the assessment of whether a test is measuring what it purports to measure, how well it does so, and the appropriateness of inferences that are drawn from the test's result and this is usually depending on factor analysis (Anastasi, 1988). Based on the factor loadings in Table 2, we deleted the items that had low item-scale correlations and had factor loadings less than 0.40.

Conclusions

This study was intended to design an instrument to identify students' perceptions of teachers' various kinds of instructional techniques that integrate diagrams in secondary biology teaching. The data analysis indicated that the instrument on students' perceptions on teachers' instructional use of diagrams has satisfactory validity and reliability. The uniqueness of this instrument is its focus on biology teachers' teaching practice using diagrams. Fraser and Tobin (1998) argued that teachers' instructional practice and beliefs influenced how they taught and implemented the curriculum, and their level of content knowledge influenced whether or not students were taught for factual retention or for understanding. In particular, for visualization to be optimally deployed in instructional materials, their semiotic, perceptual, and cognitive characteristics and their relationship to textual elements need to be synthesized and operationalized (Scheiter, Wiebe, & Holsanova, 2009, p. 74). Scheiter et al. (2009) further stated that learning and teaching with visualizations should specify the conditions under which visuals will be beneficial to students' learning outcomes; teachers also need to pay attention to the role of learner characteristics in the visual learning environment.

This instrument could help teachers identify students' perceptions on their own diagrammatic teaching in terms of their Instructional Repertoire, Assessment Repertoire, and Understanding of Students' Diagrammatic Competence. By analysing the results from administration of the questionnaire, researchers and teachers can examine how those factors are employed in the instructional use of diagrams in biology class and what needs to be improved. By paying attention to those dimensions mentioned above, it is likely that a better understanding of students' perceptions of science teachers' teaching performance with diagrams will be achieved.

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Appendix

Students' perceptions on science teachers' use of biology diagrams

Directions for students:

- This questionnaire contains statements about the teaching of biology in your class.
- The statements refer to biological topics such as respiration, photosynthesis, etc.
- You will be asked what you yourself think about these statements. There is no 'right' or 'wrong' answer. Your opinion is what is wanted.
- Think about how well each statement describes what this class is like for you.
- For each statement, draw a circle around

1 if you STRONGLY DISAGREE with the statement;
2 if you DISAGREE with the statement;
3 if you are NOT SURE;
4 if you AGREE with the statement;
5 if you STRONGLY AGREE with the statement.

Be sure to give an answer for all questions. If you change your mind about an answer, just cross it out and circle another.
Some statements in this questionnaire are fairly similar to other statements. Don't worry about this. Simply give your opinion about all statements.

Instruction with Diagrams		Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree
1	My teacher uses different kinds of diagrams to help me understand biology concepts.	1	2	3	4	5
2	My teacher's use of a variety of diagrams enables me to have a better understanding of a certain biological concept.	1	2	3	4	5
3	My teacher uses a variety of diagrams when we study different biology topics.	1	2	3	4	5
4	My teacher uses diagrams that are familiar to me to explain biology concepts.	1	2	3	4	5
5	My teacher uses analogies with which I am familiar to help me understand a particular diagram.	1	2	3	4	5
6	My teacher's teaching methods make me think hard about a particular diagram.	1	2	3	4	5
7	My teacher's methods of teaching with diagrams keep me interested in science.	1	2	3	4	5
8	My teacher provides opportunities for me to draw diagrams expressing my point of view.	1	2	3	4	5
9	My teacher shows how the diagram explains the written text.	1	2	3	4	5
10	My teacher shows how the written text helps explain a biology diagram.	1	2	3	4	5

Assessment with Diagrams						
11	My teacher's tests evaluate my understanding of diagrams of a biology topic.	1	2	3	4	5
12	My teacher's questions evaluate my understanding of diagrams while the teaching is in progress.	1	2	3	4	5
13	My teacher's tests allow him/her to check my understanding of diagrams.	1	2	3	4	5
14	My teacher assesses the extent to which I understand a diagram.	1	2	3	4	5
15	My teacher uses models to help me understand biology diagrams.	1	2	3	4	5

Students' Diagrammatic Competency		Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree
16	The biology concepts shown in a diagram can be static or kinetic.	1	2	3	4	5
17	The process of going from less abstract diagrams to more abstract diagrams suits my learning better.	1	2	3	4	5
18	When I can explain a biology concept with different types of diagrams, I feel more confident about my learning.	1	2	3	4	5
19	Diagrams are made up of a certain amount of detail, which requires special skills to interpret.	1	2	3	4	5
20	Diagrams have a role to play in bridging the gap between what I already know and the biology knowledge that I am going to learn.	1	2	3	4	5