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Learning nanotechnology with texts and comics: the impacts on students of different achievement levels

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ABSTRACT

Comics are popular with adolescents because of their features of humor, narrative, and visual imagery. The purposes of this study were to examine the learning outcomes and emotional perceptions of reading a science comic book and a science text booklet for students of different levels of achievement, and to explore the main factors of the two media which attract high-school students to learn science. A mixed-method quasi-experimental design was adopted. The participants were 697 grade ten students from eight schools with different levels of academic achievement. Two similar classes in each of the eight schools were assigned as the comic group or the text group. The results indicated that the science comic book benefited medium achievers more than the science text booklet did, but the contrary result was found for the high achievers. In comparison, the two media benefited the low achievers equally, but both had only a limited effect due to the students' lack of prior knowledge. We conclude four kinds of evidence, including perceived difficulty of comprehension, reasons for interest/disinterest, emotional perceptions of learning science, and learning time, to support the phenomenon of the learning benefit of media specific to certain achievers' science learning.

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KEYWORDS
Interest in science learning; knowledge of nanotechnology; science comics

Abbreviations

PKNT: public knowledge of nanotechnology;
PANT: public attitudes toward nanotechnology;
PEPSL: public emotional perception of science learning

Introduction

Helping learners develop interest and engagement in science is an essential issue in science education for improving scientific literacy for all. Our previous study revealed that 15-year-old students' interest and enjoyment in science are dominant factors influencing their engagement in science and their future intended interest in science compared with their scientific competency (Lin, Lawrenz, Lin, & Hong, 2013). This finding has prompted science educators to emphasize students' interest and enjoyment in learning science rather

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than merely their development of concepts and skills. Moreover, students' interest in science influences their choices of scientific careers (Krapp, 2000). Young people's interest in scientific careers is declining in the developed nations, including Japan and England, a situation which may impact the national development of science-related industries, research, and policy in the future (Essim, 2014; Osborne & Dillon, 2008; Rocard et al., 2007). Thus, science educators have the responsibility to explore effective approaches for enhancing students' interest in and enjoyment of learning science.

Printed media (e.g. books, magazines, and newspapers) are some of the most popular sources of information for informal science learning (Falk, Storksdieck, & Dierking, 2007). In particular, adolescents often read printed media in informal contexts to extend their knowledge and vision of the world. Among a variety of printed media, science texts, which are articles written specifically to explain or explore a scientific idea, are often used for science communication. Recently, science comics using humorous illustrated narratives to convey scientific information have been deemed as a potential medium of science communication. Accordingly, the specific features of humor, narrative, and visual representation in comics may enhance learners' interest and enjoyment (Authors, 2015a; Roesky & Kennepohl, 2008; Tatalovic, 2009) as well as their understanding of science (Roesky & Kennepohl, 2008; Weitkamp & Burnet, 2007). Although the use of science texts and science comics has been recommended in informal science learning, few studies have explored the effect of using the two media in informal contexts for adolescents. The purposes of this study were therefore to examine the effects (cognitive and emotional) of science texts and science comics on the informal science learning of low, medium, and high achievers, and to explore the factors which interest or fail to interest students of different levels of achievement when reading science texts or science comics. It is worth informing science communicators whether different achievers benefit from or have different preferences for the two kinds of printed media so as to accommodate learner differences.

Effective designs for different learners

Although the representation and features of science texts and science comics for conveying scientific information are rather different, some design principles are similar, for example, making text (or comic scripts) more readable, satisfying learners' psychological needs for success, and connecting with learners' prior knowledge (Currie, 1990; Gijlers & De Jong, 2005; Hamrick & Harty, 1987; Roesky & Kennepohl, 2008; Rosenshine & Mattleman, 1970; Tatalovic, 2009). However, the two printed media should be based on their specific features to design the learning materials for a variety of learners' learning needs and preferences. Thus, the research literature regarding texts and comics supporting science learning will be reviewed briefly to establish a theoretical framework for this study.

Science texts

In general, texts are classified into three types: factual/informational, narrative, and poetic text (Fountas & Pinnell, 2006). Most science texts are written as factual text. The purpose of science texts is for the authors to intentionally convey scientific information through specific text structures (e.g. description, comparison/contrast, relationship statements of

cause and effect, questions and answers) to readers to build meaning of specific ideas (Duke, 2004; Maatta, Dobb, & Ostlund, 2006. When an author writes or revises a text, the action of identifying the learning objects of the text, understanding readers' needs, and using metacognitive skills would be able to determine the information written in the text and produce a readable text (Duke, 2004; Englert, Raphael, Fear, & Anderson, 1988). In addition, there are some ways to present information to make it more readable, including using titles and subtitles to organize the content, adopting figures and tables to enhance the meaning of the text, and presenting scientific facts to change readers' beliefs (Fountas & Pinnell, 2006). An empirical study indicated that re-sequencing science texts with clear content structure and interrelationships among major concepts would benefit students' science achievement and interest in science (Hamrick & Harty, 1987).

To develop reading materials for low achievers, Rosenshine and Mattleman (1970) found that the usefulness of the information and the students' psychological needs for success are both critical. Moreover, simplified texts can significantly improve low achievers' reading (Currie, 1990). Learners actively construct their understanding by connecting new knowledge with their prior knowledge (Bell, Lewenstein, Shouse, & Feder, 2009). Some scholars have suggested that novices who have little prior knowledge in a new domain (e.g. nanotechnology) should be provided with 'well-structured' reading material, such as material which provides a gradual introduction and examples (Jonassen, 1997; Sweller, 2003). An introduction and examples including learners' prior knowledge and life experience would make them feel that the material is readable and useful in their life. In sum, specific text structures, editing strategies, consideration of learners' prior knowledge, and psychological needs are key features of developing a readable science text.

Science comics

Comics are one of the most popular media for adolescents because they make reading enjoyable and comprehensible (Liu, 2004; Weitkamp & Burnet, 2007). According to the definition of Varnum and Gibbons (2001), comics are 'a narrative form consisting of pictures arranged in sequence' (p. xvi). Based on the length and level of the narrative complexity, the forms of comics include short comic strips, comic books, and graphic novels (Tatalovic, 2009). Different forms of comics, which are able to combine the specific features of comics, namely humor, narrative, and visuals (Lin, Lin, Lee, & Yore, 2015; Weitkamp & Burnet, 2007), have been used by educators to improve student learning. For example, Liu added comic strips into a high-level text to significantly improve low-reading-level students' comprehension, rather than providing a high-level text only. However, the previous approach did not enhance high-reading-level students' comprehension. Liu emphasized the functions of visuals in comic strips, including representation, organization, interpretation, transformation, and decoration. Levin, Anglin, and Carney (1987) found that all functions benefit memory except for decoration, because the visuals always emphasize part of the text's content. Weitkamp and Burnet emphasized the function of humor in developing a comic strip, *The Chemedium*, in the UK primary science curriculum. This comic strip made students more engaged in a reading- and discussion-based activity, especially boys.

Lin et al. (2015) combined the functions of humor (visual and textual), narrative, and visuals to develop a comic book, *Knowing nanotechnology via comics*, to improve the

public's interest in learning nanotechnology. In this comic book, the characters' dialogue, which reflected readers' questions and presented the authors' explanations, was found to enhance public trust in scientists and attitudes toward nanotechnology. Some scientific comic books regarding the environment, science, and health education have been produced in developed countries, such as *The adventures of Archibold Higgins* (French), *Max axiom* (U.S.A.) and *Water heroes* (Canada) (Tatalovic, 2009). Graphic novels are one form of comic with longer texts and fewer drawings. Some famous graphic novels have been produced such as *The war of the worlds* (U.K.), *Clan Apis* (U.S.A.) and *Fallout* (U.S.A.) (Tatalovic). However, few studies have investigated the effects of these popular comic books and graphic novels on science communication.

Purpose

Science comics are considered by some science educators as an important means of conveying scientific information in an attractive, accurate, and comprehensible way (Roesky & Kennepohl, 2008; Tatalovic, 2009; Weitkamp & Burnet, 2007). However, our earlier study found that a science comic book had similar cognitive effects to an informational text (words only) booklet for the public (Lin et al., 2015). We suspected that science comics would benefit medium and low achievers' learning of science. About 90% of adolescents in Taiwan read comic books, and more than 40% have indicated that comic books are their favorite of a variety of printed media (Su, 1994). However, few science comics have been printed in Taiwan. Rather, science texts are the most familiar media for adolescents to receive scientific information. Before the development of science comics for science communication, it is worth examining whether different levels of achievers prefer specific media to learn science in informal contexts, and whether there are various effects of using the two printed media.

Several nations developing nanotechnology have been emphasizing K-16 nanotechnology education, including Taiwan. In Taiwan, the key concepts of nanotechnology have been included in the grades 11 and 12 formal science curriculum guidelines, such as nano-scale and the properties, manufacture, and application of nano-materials (Ministry of Education, 2009). Hence, nanotechnology is the best case for comparing 10th graders' learning effects and emotional perceptions of reading science comics and science texts in informal learning contexts. In this study, a comic book and a text booklet were developed by the authors to help those with basic science knowledge (about grade 9 level science) to understand nanotechnology. Thus, the purposes of this study were to examine different achievers' learning outcomes and emotional perceptions of learning nanotechnology, and to explore the main factors of attracting different level achievers to learn science through reading the two media. The research questions underlying this study were:

1. Did the comic group and the text group improve their knowledge of nanotechnology after learning? Were there differences in the two groups' improvement of knowledge?
2. Was the comic book or the text booklet specifically beneficial to certain achievement groups in informal science learning?
3. What evidence would possibly support the learning benefit of media specific to certain achievers?

Method

A mixed-method quasi-experimental design was adopted for the study. The quantitative component focused on evaluating the effects of the two media on 10th graders using a pretest and a posttest. The qualitative component involved analyses of the questionnaire and interviews obtained after learning.

The comic book and the text booklet

The comic book and the text booklet were developed and validated by the authors with the aim of helping those with a grade 9-level science background to understand nanotechnology (Lin et al., 2015). Both printed media conveyed the same key ideas of nanotechnology, but presented the scientific information through different representations. The 10-page text booklet focused on textual representation to present concrete and understandable scientific words through text structures, examples, questions and titles, while the 109-page comic book emphasized visual and textual representations to build knowledge of science occurring in interesting daily life contexts through dialogue, humorous cartoons, and scientific pictures. That is, the out-of-context scientific text in the text booklet was transformed into comic scripts in which the storyline provided life contexts, dialogues addressing readers' possible questions, discussion, experts' explanations and interesting conversations, and drawings which enhanced the scientific phenomena, explanations and enjoyment of learning (see Appendix 1 for a one-page example from the comic book).

The themes in the printed media included (1) the lotus effect and its application, (2) the biological compass and its application, (3) targeted therapy, (4) nano-photocatalysts, (5) the definition of nanotechnology, (6) specific properties of nano-scale materials, (7) introduction of measurement tools in the nano-world, and (8) the possible risks of nanotechnology. These themes include essential concepts of nano-scale science and technology which have been identified by the expert community (Sakhnini & Blonder, 2015; Stevens, Sutherland, & Krajcik, 2009). For example, innovation and application of nanotechnology (e.g. mimicking nature, phenomena, principles and application of nano-particles in medicine, and of nano-photocatalysts in environmental cleaning), size and scale, size-dependent properties, tools and instrumentation (e.g. scanning probe microscope, atomic force microscope), force and interaction, as well as the benefits and risks of nanotechnology were included. That is, the essential concepts which were related to natural phenomena and nanotech applications in everyday life and which are suitable for people with a grade 9 science background to learn were integrated into the text and the comic scripts. Using the fourth theme, nano-photocatalyst, as an example, one of the major goals is to facilitate student understanding of the principle and application of nano-photocatalysts in environmental cleaning. In both the comic book and the text booklet, students are shown how nano-scale Titanium dioxide can be accelerated by UV light to oxidize the surrounding water and create hydroxyl radicals. It can also oxidize oxygen or organic materials directly. Therefore, Titanium dioxide can be added to paints, windows, and tiles or other products for its sterilizing and deodorizing properties.

Participants and data collection

The participants involved in this study were 720 10th grade students (aged 15–16, 47% boys and 53% girls) in two administrative regions of central Taiwan. Based on the variability of schools and the population of branches in the two areas, four academic schools, three vocational schools, and one college with different Percentile Rank (PR) values were recruited to participate in this study. Two similar classes in each school were randomly selected and assigned as the text group or the comic group. The first author invited and encouraged the students to learn about nanotechnology with the assigned printed media (i.e. text or comic book) at home through explaining the study purpose. The students volunteered to participate in this study, that is, they learned nanotechnology in an informal learning context. Although the students probably perceived the assignment as formal, the design of the learning material was intended to provide sufficient time (i.e. one week) and the opportunity of autonomous learning. When the impacts of the two printed media on different achievers were investigated, the participants were divided into three groups according to the PR values of their school entrance examination scores: high achievers (PR values > 75, $n = 183$), medium achievers (PR values = 25–75, $n = 356$), and low achievers (PR values < 25, $n = 181$).

The comic group and the text group were provided with either the comic book or the text booklet, respectively, for one week. When the participants learned about nanotechnology with the assigned printed media out of school hours, they were asked to record their learning time honestly and answer two open-ended questions on a learning record sheet for the confirmation of their learning. To enhance the trustworthiness of the data, responses that presented incomplete information regarding their learning record or which gave no response to the two open-ended questions were judged as questionable data. After the deletion of these data, the 697 acceptable responses (text group: 340, comic group: 357) were analyzed.

Before and after the intervention with the assigned printed media, the participants were recruited to complete the two instruments, the Public Knowledge of Nanotechnology (PKNT) test and the Public Emotional Perceptions of Learning Science (PEPLS) questionnaire, as pretests and posttests. In addition, seven short-answer questions accompanied the instruments in the posttest to investigate the reasons for the participants' interest, their learning difficulties, their choice of medium for learning about nanotechnology, and their ideas regarding the strengths and weaknesses of the medium they had experienced. Furthermore, 30 participants (text group: 12, comic group: 18) were invited to take part in semi-structured interviews after the initial data analysis to enhance the interpretation of the quantitative data, and a diagnosis interview to identify the low achievers' learning difficulties when reading the two media.

Instruments

The PKNT test and the PEPLS questionnaire have been validated in previous studies (Lin, Lin, & Wu, 2013; Lin et al., 2015). The PKNT test consists of 26 multiple-choice items to assess learners' knowledge of six big ideas in nanotechnology, including size and scale (4 items), structure of matter (6 items), size-dependent properties (4 items), forces and interactions (6 items), tools and instrumentation (3 items), and science-technology-

society (4 items). Overall the KR-20 reliability of the PKNT was 0.91 for the validation sample. For the current pretest and posttest, the KR-20 reliabilities were 0.75 and 0.85, respectively.

The PEPLS questionnaire was developed to measure the effect of the learning intervention on the learners' emotional perceptions of science learning in an informal learning context. The questionnaire consisted of two subscales: enjoyment and interest. Each subscale included six 4-point Likert scale items. The Cronbach's α for the PEPLS was 0.94 for the validation sample. In the current pretest and posttest, the Cronbach's α values were both 0.94.

Data analysis

Paired *t*-tests were used to examine the effect of the two media on the participants' knowledge of nanotechnology and their emotional perceptions of learning science. The analysis of covariance (ANCOVA) was conducted to examine the media effects. The qualitative data were coded and classified for descriptive statistics. In order to investigate the participants' reasons for being interested or uninterested in reading their assigned materials, a coding scheme including four positive and four negative reasons was developed as shown in Appendix 2. Two trained coders coded the participants' responses independently. The inter-rater reliability of exact category agreement was 99.3%.

Results

Did the comic group and the text group improve their knowledge of nanotechnology after learning? Were there differences in the two groups' improvement of knowledge?

The paired *t*-test results of the PKNT indicated that the text and comic groups made significant improvements in their knowledge of nanotechnology through reading the assigned media ($t_{text} = 15.66$, $p < .001$; $t_{comic} = 18.88$, $p < .001$), with rather high effect size values ($d_{text} = 0.79$, $d_{comic} = 0.92$). Obviously, the text booklet and the comic book benefited the grade 10 students' learning of nanotechnology in an informal context. To examine which medium induced better learning effects, the pretest means were used as the covariate to adjust for the two groups' initial difference. The ANCOVA result revealed that there was no significant difference in the improvement in nanotechnology knowledge ($F = 0.781$, $p = .377$). In brief, both media were similarly effective in terms of communicating scientific concepts.

Was the comic book or the text booklet specifically beneficial to certain achiever groups in informal science learning?

Table 1 provides the means and standard deviations of the pretest and posttest PKNT scores, and the *t*-value of the three different achievement groups through reading the comic book or the text booklet. All paired *t*-test results of the PKNT in Table 1 indicate that all three achievement groups made significant ($p < .001$) improvement in their nanotechnology knowledge through reading the comic book or the text booklet. In order to

Table 1. Means, SDs and paired *t*-test results of the PKNT pre- and posttest and the ANCOVA results of the text and comic groups for high, medium and low achievers.

	Group	*N*	Pretest *M* (SD)	Posttest *M* (SD)	*t*	*p*	Adjusted	*F*	*p*	Note
High achiever	comic	91	9.45 (3.63)	13.62 (4.65)	9.172	.000	13.53 (0.45)	5.620	.019	Text >
	text	92	9.09 (4.16)	14.95 (4.62)	10.972	.000	15.03 (0.45)			Comic
Medium	comic	176	9.26 (3.67)	14.18 (4.01)	16.105	.000	14.41 (0.26)	15.268	.000	Comic >
achiever	text	176	10.15 (3.91)	13.19 (3.95)	10.825	.000	12.96 (0.26)			Text
Low achiever	comic	90	5.73 (3.26)	8.07 (3.91)	6.747	.000	7.88 (0.36)	0.002	.962	
	text	72	5.18 (3.48)	7.67 (4.64)	5.749	.000	7.90 (0.40)			

examine whether the two media had similar learning effects for each achievement group, ANCOVAs using the pretest mean as the covariate to adjust the two media groups' initial difference revealed that the text group progressed significantly more than the comic group for the high achievers ($F = 5.620$, $p = .019$), but the comic group progressed significantly more than the text group for the medium achievers ($F = 15.268$, $p < .001$). However, the two groups of low achievers had similar learning effects ($F = 0.002$, $p = .962$).

Figure 1 shows the improved PKNT mean scores (i.e. the improved PKNT = posttest score − pretest score) of the two media groups for each achievement group. It is obvious that the high achievers reading the text booklet progressed significantly more than those reading the comic book ($t = 2.637$, $p < .01$). By contrast, the medium achievers reading the comic book progressed significantly more than those reading the text booklet ($t = 4.302$, $p < .001$). Thus, the text booklet seems to be more beneficial for high achievers' learning, while the comic book is more beneficial for medium achievers in an informal

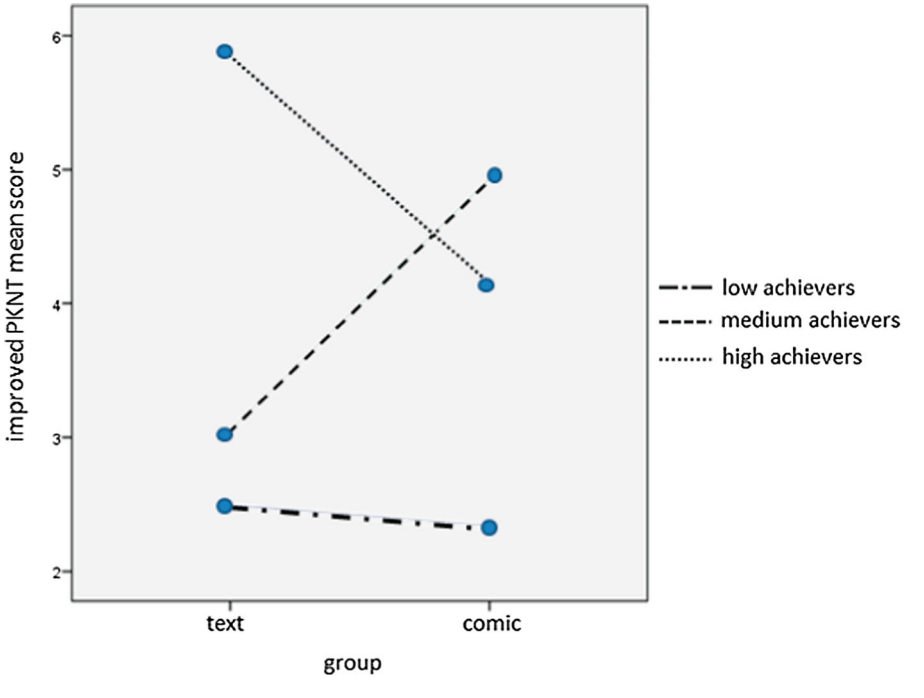

Figure 1. The improved PKNT mean scores of the low, medium and high achiever groups after reading the text booklet and the comic book.

learning context. One high achiever indicated that, 'Science texts transmit scientific information directly, but narratives in science comics transmit scientific information indirectly' (text_201130). Moreover, one student who preferred the science text responded that, 'Because a comic book contains few words, I often review it quickly. However, I think there is more content and useful knowledge in a text, so I will usually read it slowly' (comic_203228). Nevertheless, most of the participants preferring comics indicated that they dislike reading texts because of all the words, while comics make them feel that the content with drawings is more interesting and easier to understand (comic_103225, comic_201217, comic_203219). In addition, one medium achiever responded, 'I prefer reading science comics to science texts, because the drawings in comics help me imagine the content more easily' (comic_103231). Scientific description and relationship statements of cause and effect are common in science texts for presenting factual and explanatory knowledge. However, brief statements in a science text need to be rewritten in a dialogical and narrative form in a long comic script. Thus, scientific information is embedded in the dialogue and story in a comic book. It is obvious that high achievers have better comprehension of and are familiar with reading brief science texts, but dialogical scientific explanation and interesting stories in comics benefit medium achievers' learning more than brief scientific statements in texts.

Compared with the high and medium achievers' PKNT pretest mean scores, the low achievers' scores were rather low (see Table 1). Moreover, their improved PKNT mean scores were not particularly high. Their lack of prior knowledge may have been a block to their comprehension. Thus, the two media improved the low achievers' knowledge similarly and only to a limited extent.

What evidence would possibly support the learning benefit of media specific to certain achievers?

When the data from multiple resources were analyzed, four kinds of evidence were found to explain the phenomenon of the learning benefit of media specific to certain achievers.

Reasons for interest/ disinterest in learning about nanotechnology

Based on the participants' responses, eight reasons were found to show the reasons why participants were interested in learning nanotechnology with the assigned media (ref. Appendix 2). Furthermore, to investigate whether the three achievement groups had different reasons for learning nanotechnology with the two media, Figure 2 presents the percentages and reasons for each group's interest or disinterest. Among four reasons for interest, 'positive factors from the media' and 'acquisition of knowledge' mainly attracted participants to learn about nanotechnology. However, among the four reasons for lack of interest, 'dislike of science/nanotechnology' was the major reason blocking participants' learning interest.

When the participants responded whether they were interested in learning about nanotechnology with their assigned media, 81.8% of the comic readers and 57.0% of the text readers responded 'Yes'. Each achievement group's percentage of interest in learning with the science comic was about 20% higher than that of interest in learning with the science text. It is noted that the percentages of the reason 'positive factors from media' were the highest among all of the positive reasons (high achievers: 60.9%, medium

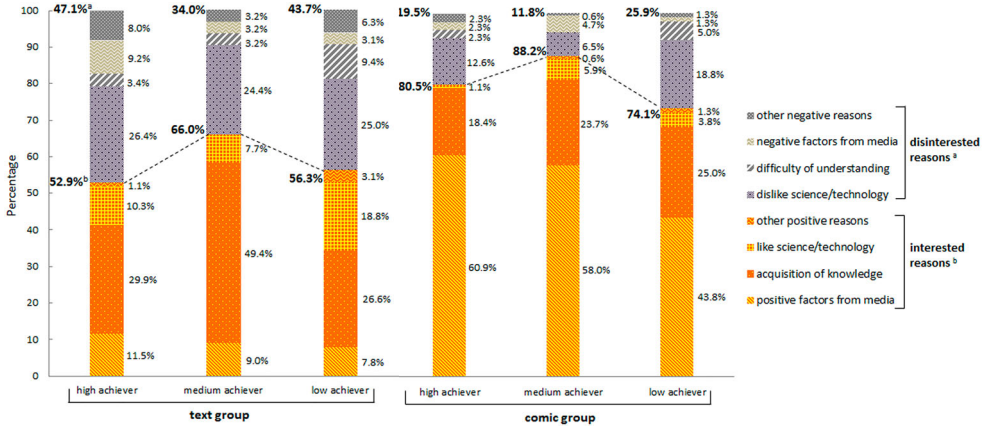

Figure 2. Percentage of reasons for interest or disinterest of different achievement levels in the text and comic groups.

achievers: 58.0%, low achievers: 43.8%) stated by the comic readers. In contrast, for the same reason as stated by the text readers, the percentages of the three groups were rather low (high achievers: 11.5%, medium achievers: 9.0%, low achievers: 7.8%). The 'positive factors from media' refer to the features of the media (i.e. humor, narrative, and visual representation) which attracted the participants to learn. It is obvious that the specific features of science comics make more students like to learn science, and not only for the medium achievers, but also for the high and low achievers as well.

Figure 2 indicates that the percentages of the reason 'dislike science/technology' stated by the three achievement groups in the text group were about 15% higher than those in the comic group. We argue that the features of science comics could decrease readers' perceptions of disliking science/technology. In brief, the abovementioned evidence indicates that the difference in printed media does greatly impact students' engagement in learning science in informal contexts.

To investigate the main reasons affecting students' engagement in reading printed media, they were asked to rank four reasons (i.e. type, topic, interesting, and understandable). Figure 3 shows the percentage of the main reasons affecting the participants' interest in learning science for the high, medium, and low achievers, respectively. The patterns of each achievement group's main reasons are rather different. For example, a plurality of the low achievers (42.8%) were affected by the media type, but a plurality of the high achievers (33.5%) were affected by the topic. As for the medium achievers, they perceived that media type (32.6%) and topic (29.6%) were similarly attractive to their engagement in reading the printed media. In order to investigate which of the two printed media was the participants' primary choice if they could select one freely, each participant could review the other printed medium which he/she did not use to learn during the posttest, and then they were asked to respond with their choice. Table 2 shows the participants' choice if they could select one of the two media to learn about nanotechnology. Science comics were the majority of participants' choice, and lower achievers selected comics more than higher achievers. In sum, media type mainly dominated the students' interest in informal science learning, especially for medium and low achievers.

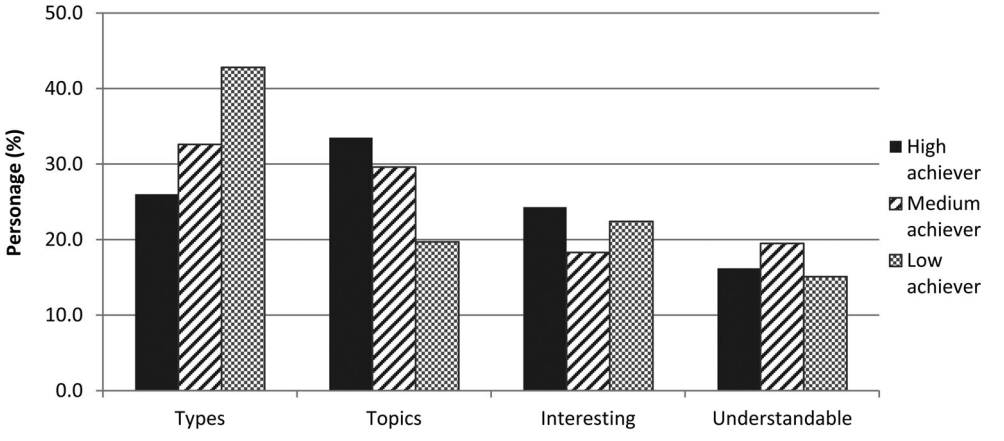

Figure 3. Percentage of main reasons affecting different achievers' interest in learning science.

Perceived difficulty in learning nanotechnology

Table 3 presents the percentages of the different achievement groups' perceptions of the difficulty of understanding the contents of the text booklet or the comic book. It is obvious that most of the participants perceived the content in the comic book as being easy to understand. However, the percentage of perceived difficulty of reading the text booklet increased as the participants' achievement level decreased. It is noted that the percentage of high achievers who perceived difficulty reading the comic book was similar to that of reading the text booklet, but fewer low and medium achievers in the comic group perceived difficulty of understanding. We argue that the high achievers had better ability to recognize their understanding in science/technology than the lower achievers, so that a similar percentage of high achievers reported the difficulty of the two media transmitting the same science concepts. However, the lower achievers overrated their understanding of the comic book. All of the low-achieving interviewees responded that the pictures and/or detailed explanations in the comic book increased their comprehension of the content 20% more than did the words in the text booklet. In fact, the results from the diagnosis interviews revealed that several unknown scientific terms and misunderstanding of the pictures still blocked the low achievers' learning of nanotechnology. In brief, the science comic using drawings, dialogues, and narratives to transmit scientific information significantly decreased the medium and low achievers' perceived difficulty of learning science.

Emotional perceptions of learning science

Table 4 provides the PEPLS pretest mean scores, standard deviations, and *t*-value of the three achievement groups through reading the comic book or the text booklet. The *t*-test results show that the PEPLS scores of all achievement groups decreased after

Table 2. Percentage of different achievers' choice between science texts and science comics.

	N	Text (%)	Comic (%)
High achiever	181	16.0	84.0
Medium achiever	347	12.6	87.4
Low achiever	159	9.5	90.5

Table 3. Percentage of different achievers' perceptions of the difficulty of understanding the content of the text booklet or the comic book.

	Comic		Text	
	N	%	*N*	%
High achiever	91	30.8	90	30.0
Medium achiever	176	23.9	172	34.9
Low achiever	89	23.6	70	58.6

reading the text booklet, but increased after reading the comic book. However, these changes were not significant. Obviously, the text booklet weakened some students' emotional perceptions of learning science, but the comic book slightly enhanced them.

To investigate whether the impacts of the two media differed, an ANCOVA using the PEPLS pretest mean scores as the covariate to adjust for the text and comic groups' initial difference was conducted (Table 4). The ANCOVA results showed that the PEPLS mean score of medium achievers reading the comic books was significantly higher than that of reading the text booklet ($M_{comic\_adj} = 32.58$, $M_{text\_adj} = 31.50$; $F = 8.320$, $p = .004$). However, the two media had a similar impact on high and low achievers' emotional perceptions of learning science. In brief, medium achievers seemed to enjoy learning with the comic book more than with the text booklet.

Learning time

Table 5 provides the mean learning time, standard deviations, and *t*-value of different achievers' learning time for the text and comic groups. It is found that the comic readers in each achievement group took more learning time than the text readers. A reasonable explanation is that there were ten times as many pages and twice as many words in the comic book as in the text booklet (comic:12,604 words, text: 6376 words). The results indicate that the mean learning time of the medium achievers reading the comic book was significantly higher than that of reading the text booklet ($t = 2.758$, $p = .006$). According to the ANCOVA results of the PEPLS for the medium achievers, the comic book could attract medium achievers more than the text booklet could. Thus, medium achievers reading the comic book spent more time learning about nanotechnology and improved their knowledge of nanotechnology more than those who read the text booklet.

Compared with the high and medium achievers, the low achievers spent rather more learning time not only reading the comic book, but also reading the text booklet. The PKNT pretest mean scores of the low achievers were noticeably lower than those of the

Table 4. Means, SDs and paired *t*-test results of the PEPLS pre- and posttest and the ANCOVA results of the text and comic groups for high, medium and low achievers.

	Group	*N*	Pretest *M* (SD)	Posttest *M* (SD)	*t*	*p*	Adjusted	*F*	*p*	Note
High achiever	Comic	91	31.69 (5.73)	31.85 (5.17)	0.423	.674	31.54 (0.37)	1.721	.191	
	Text	92	30.80 (6.11)	30.57 (5.46)	−0.526	.600	30.87 (0.36)			
Medium achiever	Comic	175	32.59 (5.87)	33.13 (5.50)	1.956	.052	32.58 (0.27)	8.320	.004	Comic > Text
	Text	175	31.19 (6.83)	30.95 (6.53)	−0.786	.433	31.50 (0.27)			
Low achiever	Comic	90	31.31 (6.23)	30.79 (5.98)	−1.132	.261	30.80 (0.62)	0.277	.600	
	Text	71	30.69 (6.83)	30.37 (5.64)	−0.604	.548	30.31 (0.69)			

Table 5. Independent *t*-test results of learning time of the text and comic groups for high, medium and low achievers.

	Comic		Text				
	N	*M* (SD)	*N*	*M* (SD)	*t*	*p*	Note
High achiever	91	58.60 (23.86)	92	49.60 (43.74)	1.732	.086	
Medium achiever	176	79.57 (83.95)	176	56.57 (75.95)	2.758	.006	Comic > Text
Low achiever	90	110.69 (99.10)	72	92.60 (75.78)	1.278	.203	

medium and high achievers (Table 1). In addition, through the diagnosis interviews, we found that the low achievers could not understand several basic scientific terms when reading not only the text booklet, but also the comic book. Thus, it is reasonable that both media might be so difficult for the low achievers because of their lack of prior knowledge of science, and therefore they took more learning time.

Discussion and conclusions

Although a majority of students preferred to select science comics as their learning medium in informal contexts than science texts, the findings clearly show that science comics are not more effective than science texts for students of all achievement levels. For medium achievers, the science comic book did benefit them more than the science text booklet, but the contrary result was found for the high achievers. In comparison, the two media benefited the low achievers equally, but both had only a limited effect. Based on the analysis of multiple data resources, we conclude four kinds of evidence to support the phenomenon of the learning benefit of media specific to certain achievers' science learning. This evidence, including perceived difficulty of comprehension, reasons for interest/disinterest, emotional perceptions of learning science, and learning time, led us to identify the intrinsic factors of students' learning with science comics and science texts. The following discussion infers three intrinsic factors including prior knowledge, specific features of media and personal learning preference, and presents the interplay of these three factors on low, medium and high achievers' science learning. The high achievers who were skillful learners to read expository texts and high-knowledge readers with the most prior knowledge could progress the most in the PKNT test through using the text booklet (Table 1). In contrast, science comics which provide scaffolding for understanding nanotechnology seem to be an obstacle preventing high achievers' effective learning and distracting their acquisition of scientific information. Our results support previous research indicating that high-knowledge readers learn more from low-coherence than high-coherence texts (McNamara et al., 1996). High-coherence texts imply that texts include added background knowledge or information to reduce coherence gaps from one proposition to the next. McNamara (2001) indicated that reading low-coherence texts promotes readers' use of prior knowledge to fill in the conceptual gaps, while reading high-coherence texts negates the need to use prior knowledge to understand the text. The comic book which presents scientific dialogue and visual representation to scaffold nanotechnology learning could be classified as a high-coherence text, while the text booklet could be seen as low-coherence text in this study. For high achievers, science texts provide appropriate conceptual gaps allowing them to recall their prior knowledge and generate inferences during the process of comprehension. High achievers used similar learning time to read both types of learning material. While text readers spent

more learning time recalling prior knowledge and constructing new knowledge, it is obvious that the amount of *active processing* during reading increased due to providing appropriate conceptual gaps. However, the comic book readers spent more time reading the dialogue, narrative, and graphics. Lack of inference in reading science comics may be the main reason for the decrease in the high achievers' learning effect. Furthermore, a significant topic or content is the major reason attracting their attention to learn science rather than the type of medium. Therefore, science texts benefit high achievers in learning science more than science comics.

However, the features of science comics (e.g. humor, narrative, and visual representation) benefit medium achievers not only in terms of the cognitive aspect, but also the affective aspect. In general, medium achievers' science comprehension ability is poorer than that of high achievers. Some studies have found that multiple representations (i.e. verbal and visual representations) for presenting learning materials contribute to constructing a mental model and promote students' concept learning (Eilam & Poyas, 2010; Mayer & Moreno, 2002). The multiple representations in the comic book should provide appropriate scaffolding to fill medium achievers' cognitive gaps due to deficiencies in their prior knowledge.

Our previous study found that the conversational language in comics was able to transform *rigid science* into *soft/simple words* to make science accessible and understandable for public citizens (Lin et al., 2015). We believe that the combination of contextualized scientific language with visual representations and humor can greatly increase medium achievers' interest in learning ($F_{\text{interest}} = 13.941$, $p < .001$). In other words, the features of science comics are beneficial for medium achievers' learning in the cognitive aspect. It is likely that science comics and nanotechnology matched the medium achievers' favorite medium type and topic in learning science in the affective aspect. These positive reasons affecting medium achievers' science learning combined to produce their higher interest in learning with the comic book than learning with the text booklet. Thus, not only were their emotional perceptions of learning science more positive, but their learning time using the comic book was also significantly longer than that of reading the text booklet. Thus, the medium achievers' learning effect (i.e. improvement of knowledge) of using the comic was better than that of using the text. In sum, science comics benefit medium achievers more than science texts.

For the low achievers, the science comic book matched their learning preference. Moreover, the specific features of comics, that is, visual representation and dialogue explanations, make them believe that science comics are more accessible and help them like to learn science in informal contexts. However, several unknown scientific terms and misunderstanding of the drawings resulted in their limited improvement in nanotechnology knowledge. Most of these unknown scientific terms should have been acquired before grade 10. That is, their lack of prior knowledge blocked the low achievers' self-learning in the informal context. Low achievers' learning time shows that most low achievers would like to learn about nanotechnology (Table 5). Because nanotechnology education has been implemented in high school science, developing alternative learning approaches such as including informal learning and examining their impacts for diverse students is important. Based on the results of this study, science comics or texts could be used as supplemental reading material to help students construct fundamental knowledge of nanotechnology. However, in order to improve low achievers' learning effect, we suggest that teachers' instruction of using

science comics and enhancing the understanding of pre-acquired knowledge should be added to assist low achievers' science learning in remedial teaching, and the learning effect of which requires further examination in future research. Furthermore, some researchers have suggested that peer discussion benefits low achievers' understanding of science concepts (Rivard, 2004). The research findings of this study support that science comics could be used as learning or teaching material in nano-education. Further research may develop learning tasks of peer discussion and writing for reading science comics, and then investigate the learning effect of cooperation for diverse levels of achievers.

The study presented in this article has two major educational implications. First, the intervention of using either the textual representation of the text booklet or the theme-based comic book was neither extensive nor time consuming. In addition, both of these two media can be used as supplemental reading material to help students construct fundamental knowledge of nanotechnology. This is especially useful for those teachers who have a crowded curriculum and teaching schedule but are still interested in integrating nanotechnology into their teaching practices (Lin, Chen, Shih, Wang, & Chang, 2015). The second way in which the study adds to the literature is that it provides insights into how the two media have different impacts on high-, medium-, and low-achieving students. The diversity of student preference and reasons for selecting reading material should be carefully considered by curriculum developers and science educators. Gilbert and Lin (2013) have indicated that popular books have the capability to make a valuable contribution to nano-education since they are available at a wide range of commercial outlets, are very flexible in their use, and include photographs and diagrams. In addition, it is clear that fundamental research on the areas of nano-education including curriculum and instructional strategies should keep pace with the advancements of nanotechnology (Jones et al., 2013). In response to the calls of the above literature, this study examined the effectiveness of using a text booklet and a comic book as media for nano-education. Further research exploring the potential benefits of different media shaping effective educational practices is encouraged.

Nowadays science texts are still the most popular type of printed medium, while science comics are still rather rare. Our study revealed that science texts merely benefit high achievers. To improve more diverse achievers' engagement in informal science learning, the development of science comics is necessary.

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Appendix 1. One-page example of Knowing Nanotechnology via Comics cited from the unit of target therapy. The original comic was in Chinese

Appendix 2. Coding scheme of participants' reasons for being interested or uninterested in reading their assigned materials

	Code	Example
Positive reasons	Positive factors from media/Easy or fun	• The book is easy to read because there are not only words. • The book transforms a lot of words into simple drawings. • The pictures make the words more understandable. • The content is related to daily life.
	Acquisition of knowledge	• I would like to know the benefits and disadvantages of nanotechnology. • I can understand the progress of technology. • It can increase my knowledge which is practical in daily life and related to our future.
	Like science/technology (science/technology is interesting or fun or practical)	• New technology is interesting. • Nanotechnology makes me curious. • I like anything related to science. • Nanotechnology provides a lot of benefits to our life.
	Other positive reasons	• The content (of the comic book) seems not to be long. • It is said that nanotechnology can speed up cleaning. • Fun!
Negative reasons	Dislike science/technology (science/technology is boring or impractical)	• I dislike reading science-related content. • It is impractical in our life.
	Difficulty of understanding	• The content is too complicated for me. • I can't understand the content. • A lot of technical terms make it hard for me to understand.
	Negative factors from media/dislike all words or comics	• All the words in the text make me fall asleep. • I don't like comics. • It (the content) is too long!
	Other negative reasons	• Let experts know them (science/technology)! • Nano products do not exist in our everyday lives yet.