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Are Science Comics a Good Medium for Science Communication? The Case for Public Learning of Nanotechnology

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Comic books possessing the features of humour, narrative, and visual representation are deemed as a potential medium for science communication; however, empirical studies exploring the effects of comics are scarce. The purposes of this study were to examine and compare the impacts of a comic book and a text booklet on conveying the concepts of nanotechnology and to investigate public perceptions of using comics as a tool for science communication. A mixed-methods quasi-experimental design was used to explore these central issues. Three instruments were adopted to assess public knowledge of nanotechnology, public attitudes towards nanotechnology, and public emotional perceptions of learning science. Furthermore, 7 short-answer questions accompanying the posttest as well as interviews were administered to enrich the instrument results. The proportional stratified sampling method was used to recruit more than 300 adults as a pool of participants. Finally, the responses of 194 participants who completed the instruments were analysed. The results indicated that the comic book significantly promoted laypeople’s knowledge of and attitudes towards nanotechnology as did the text booklet. It is noted that the comic book increased the participants’ interest in and enjoyment of learning, while the text booklet decreased their interest and enjoyment. More comic readers were interested in learning nanotechnology via comics than text readers were interested in learning via text. Although there was no significant difference between the 2 media in the aspects of knowledge and attitude, the results of emotional perceptions imply that science comics have the potential to develop laypeople’s ongoing interest and enjoyment for learning science by reading comics.

Keywords: Attitudes towards nanotechnology; Informal environments; Interest in science learning; Knowledge of nanotechnology; Science comics

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Introduction

Public engagement in science and science communication are gradually being emphasised in many countries. Print media (e.g. books, magazines, and newspapers) and other media (e.g. Internet, TV, and museums) are the main sources of information for informal science learning (Falk, Storksdieck, & Dierking, 2007). Among the popular media, print media have the capability of making a valuable contribution to science communication because they are available at a variety of locations, such as train stations, supermarkets, and bookstores (Bell, Lewenstein, Shouse, & Feder, 2009; Gilbert & Lin, 2013). Although printed media have a long history in science communication, few studies have explored the effects of different types of printed media on science learning.

Learners’ interest and enjoyment in science are dominant factors that influence their engagement in science (Lin, Lin, & Wu, 2013). Science communicators have the responsibility to find effective media that are able to induce people’s interest and enjoyment in science. Amongst a variety of printed media, comics are deemed as a potential means of conveying scientific information, because humour, the specific feature of comics, may attract many people’s attention, interest, and enjoyment (Roesky & Kennepohl, 2008; Tatalovic, 2009). Varnum and Gibbons (2001) defined comics as ‘a narrative form consisting of pictures arranged in sequence’ (p. xvi). Common forms of comics include short comic strips, comic books, and graphic novels. These forms vary in their length and level of narrative complexity (Tatalovic, 2009). Hence, science comics refer to a medium using humorous illustrated narrative to transmit scientific information. Previous studies revealed that humour can enhance readers’ positive emotional and intrinsic motivation to improve their interest in and learning of science (Chen & Hsu, 2006; Roesky & Kennepohl, 2008). Besides humour (embedded in visual and textual representation), the features of visual imagery and narrative in comics make science more understandable, imaginative, and popular. Therefore, 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).

The impacts of new technologies on personal, social, and economic aspects of people’s existence have been revealed in the histories of atomic energy and biotechnology (Kurath & Gisler, 2009). It is important that adults learn about new technologies to make wise decisions on purchases, financial investments, and policy judgements of new technologies and to decrease environmental and human health hazards flowing from these technologies. Nanotechnology has been one of the most important scientific developments in decades. Moreover, there are several products labelled as ‘nanotech’ in markets. However, the majority of people in several developed countries (e.g. the USA, England, Japan, and Taiwan) lack even basic understanding of this emerging technology (Cobb & Macoubrie, 2004; Dowling et al., 2004; Lin, Lin, & Wu, 2013). In order to avoid the repetition of hazards of other technologies, it is important to communicate the benefits and risks of nanotechnology to the public. Without such...
public awareness efforts, people may be destined to the dangerous techno-scientific events of history.

Although science education researchers deem comics as a potential tool for science learning, studies exploring the effects of comics on science communication for the public are scarce, especially for communicating about new technologies. The purposes of this study were to develop and evaluate the effects of a comic book entitled *Knowing Nanotechnology via Comics* and of a traditional text booklet with the same focus and content on public knowledge of and attitudes towards nanotechnology and public perceptions of learning science.

**Comics in Science Education and Communication**

The development of science comics has been based on three considerations for improving science learning: learning through humour, contextualised learning, and visualised learning. First, humour is the most specific feature of comics that can induce learners’ intrinsic motivation and promote learning engagement (Chen & Hsu, 2006) and improve learning (Kher, Molstad, & Donahue, 1999). Humour can stimulate learners’ positive emotions that facilitate their attempts to learn and produce more creative thoughts (Chen & Hsu, 2006; Fiedler, 1988).

Second, previous studies have revealed that students have difficulty transforming knowledge learned in school science into application in everyday life—knowing does not ensure use. Decontextualised learning materials and activities in school science may be the main reason for these difficulties of transformation (de Jong, Specht, & Koper, 2007). Furthermore, the transfer and application of basic chemistry and physics ideas to modern technologies may occur in informal learning for most adults since nanotechnology has been developed after they left school. However, nano-products and phenomena related to nano-science are part of their everyday life. Science communicators can use these everyday nanotechnologies to stimulate adults’ curiosity about the basic principles of nano-products and phenomena. Comics are deemed as an effective medium of contextualised learning because they are a narrative genre consisting of pictures and words. Narrative can be created with scientific phenomena and dialogue in real-life events/contexts in which learners would understand the relationship between science and real life (Rollnick, Jones, Perold, & Ann Bahr, 1998; Weitkamp & Burnet, 2007). Moreover, to convey the safety of experimental laboratories and discuss issues of scientific ethics, it is necessary to provide opportunities for reflection in context (Tatalovic, 2009; Weinstein, 2006). Newton (2002) suggested that stories can provide a context for proposing questions or explanations to help people learn scientific concepts.

Third, comics provide learners with visualised learning combining visual representation and scientific explanation. ‘Did you look at the cartoons before reading the text?’—this question points out the attractive feature of comics’ visual representation (Roesky & Kennepohl, 2008, p. 1355). Scientific explanation and application in comics can be presented by the combination of visual and verbal representations. The use of visual representations enhances the understanding of the text (Eilam & **
Moreover, information represented with pictures can be retained in and picked up more easily from memory (Anderson, 1978; Paivio, 1971). Although comics and book illustrations are similar in the combination of text and images, text and images in comics are more closely associated and connected than those in books (Tatalovic, 2009). The possible reasons may be that comics use several different modes of visual representations (e.g. gestural, verbal, and symbolic), integrate living and scientific dialogue and notes for images, and use speech bubbles to indicate explicitly connections to the speaker or illustration. Thus, comics are deemed as a good tool to communicate science. However, Tatalovic (2009) argued that, if science is made to be fun by the use of impressive artwork and humorous dialogue in comics, the artwork and plot of dialogue might discount the effect of conveying the scientific ideas. Hence, it is worth examining the effects of comics in science communication.

Empirical studies that have investigated the effects of comics in science education and communication are limited. Previous studies have revealed some positive effects; for example, children using comic strips as their teaching materials, particularly boys, engaged more in reading and discussion-based activities (Weitkamp & Burnet, 2007). There is also some evidence that comics enhance students’ memory of concepts (Nagata, 1999). Moreover, comics have been found to be a good medium in medical/health communication (Delp & Jones, 1996; Houts, Doak, Doak, & Loscalzo, 2006). Delp and Jones (1996) indicated that more patients given comics read the medical care instructions at home than those who were given text (98% vs. 79%, $p < .001$), and the comics readers were able to answer more questions correctly (46% vs. 6%, $p < .001$) and follow the instructions at home (77% vs. 54%, $p < .001$) than traditional text readers.

Several common comics have been used to convey environmental and laboratory safety information and scientific ideas and facts through detailed explanation in references or extra published books (e.g. The science of superheroes [Gresh & Weinberg, 2002] and The physics of superheroes [Kakalios, 2005]). Tatalovic (2009) indicated that several fiction superhero comics have more entertainment value than non-fiction ones, but the former often gets the science ‘facts’ wrong. Wignall (2005) suggested that fiction comics use a combination of science, magic, legend, and mythology in their storylines. In contrast, non-fiction stories are based on commonly accepted facts and information. Thus, Tatalovic (2009) suggested using non-fiction comics to get the science right and that retaining the features of humour, context, and visualisation would be a good tool for communicating science.

Public Knowledge of and Attitudes Towards Nanotechnology

Currently, much of the evidence from the countries developing nanotechnology has shown that most people lack basic understanding of this technology. For example, more than 60% of the general population in the USA does not know what nanotechnology is (Cobb & Macoubrie, 2004; Kahan, Slovic, Braman, Gastil, & Cohen, 2007; Macoubrie, 2005); only 20% of the general population in England and Japan can give
a simple definition of nanotechnology, which often contains mistakes (Dowling et al., 2004; Fujita, Yokoyama, & Abe, 2006). Knowledge about nanotechnology developed by scientists has increased drastically after the mid-2000s, but the public understanding of nanotechnology has not changed apparently. For example, in Taiwan, more than 60% of the public do not demonstrate a basic understanding of nanotechnology (Cheng, Lin, & Chou, 2008) and more than 80% of the public in France reported unfamiliarity with nanotechnology (Vandermoere, Blanchehance, Bieberstein, Marette, & Roosen, 2011). Hence, nanotechnology is a good case to investigate how adults learn about new science and technology as there are currently low levels of understanding (Lin, Hong & Chen, 2013).

What knowledge of nanotechnology is essential for the public? Stevens, Sutherland, and Krajcik (2009) proposed nine big ideas about nanoscale science and engineering for nanotechnology education: size and scale, structure of matter, size-dependent properties, forces and interactions, tools and instruments, science-technology-society (STS), quantum effects, self-assembly, and models and simulations. The first six ideas have been identified as necessary knowledge for scientific citizenship. An instrument for assessing Public Knowledge of Nanotechnology (PKNT) was subsequently developed and validated (Lin, Lin, et al., 2013).

Attitude refers to an individual’s positive or negative feeling towards something—one likes or dislikes something (Edwards, 1994). Some studies have revealed that people’s decisions to buy certain emerging technology products or to support the research funding for that technology are mostly based on their feelings rather than on analytical judgements (Lee, Scheufele, & Lewenstein, 2005; Rodriguez & Peterson, 1999). Furthermore, public attitudes towards emerging technologies may greatly impact the development of the technology (Ferber, 1999). Thus, the assessment of Public Attitudes towards Nanotechnology (PANT) should be considered in the development of nanotechnology and nanotechnology education.

Most of the studies with respect to assessing public attitudes towards technology have focused on the dimension of trust in government agencies, in business and industry, and in scientists (Cobb & Macoubrie, 2004; Lee, Scheufele, & Lewenstein, 2005; Rodriguez & Peterson, 1999) and the perceptions of the technological benefits and risks (Frewer, Howard, & Shepherd, 1998; Ghosh, McGuckin, & Kumbhakar, 1994; Lee et al., 2005). Researchers have revealed that those people who lack trust in business leaders and scientists are likely to perceive more risks than benefits (Cobb & Macoubrie, 2004; Lee et al., 2005). A majority of American laypeople perceive nanotechnology as a high-benefit, high-risk technology (Cobb & Macoubrie, 2004; Siegrist, Keller, Kastenholz, Frey, & Wiek, 2007). Roco (2003) predicted that nanotechnology has great potential for creating jobs and fostering economic development. Therefore, further education of nanotechnology’s potential benefits and risks in terms of the environment and individual health is needed. Science communicators have a responsibility to transmit understandable information regarding scientists’ new findings and the development of products related to human life, and government policies about the management of nanotechnology products to enhance the trust of the general public.
Public Perceptions of Learning Science

Schools are an important source of science learning, but it is not the primary source for most adults. Falk et al. (2007) indicated that ‘nearly half of the public’s self-reported science understanding derives from leisure time, free-choice learning’ (p. 455). Moreover, once people leave school, science learning is based on motivation related to their interest, need, and curiosity. The main reasons why adults visit national parks or science centres are to fulfil their need for relaxation and enjoyment and to satisfy their intellectual curiosity (Brody, Tomkiewicz, & Graves, 2002; Falk et al., 2007; Heimlich, Bronnenkant, Barlage, & Falk, 2005). The satisfaction of curiosity brings an individual enjoyment. Furthermore, the analysis of the Programme for International Student Assessment (PISA) 2006 database revealed that learners’ interest and enjoyment, rather than their science competency, were the major factors influencing their engagement in science and learning specific science content knowledge in the future (Lin, Lawrenz, Lin, & Hong, 2013). These findings support the argument that emotional factors such as interest and enjoyment play key roles in lifelong science learning (Azevedo, 2004; Falk et al., 2007).

Interest refers to a mental state of curiosity or concern about or attention to an object, subject, or activity (Krapp, 2002). Based on the development of learner interest (Hidi & Renninger, 2006), individual interest can be developed from situational interest, which is triggered and maintained by novel, interesting, and challenging activities. Individual interest is long term and stable, while situational interest is a short-term preference generated by certain novel experiences. A comparison of interest in science between 15-year olds and adults revealed that the percentages of the two groups interested in learning science were relatively similar and that both groups’ interest in human biology was higher than that in chemistry (Lin, Hong, & Huang, 2012). Furthermore, the interest of 15-year olds in science was the key factor influencing their learning of specific science content knowledge in the future (Lin, Lawrenz, et al., 2013). Hence, to improve adults’ interest and engagement in nanotechnology-related issues in the future, fostering their current interest in learning nanotechnology is important.

Enjoyment is another factor related to self-learning engagement (Laukenmann et al., 2003; Lin, Lawrenz, et al., 2013). The experience of joy and positive emotion in learning is related to learning performance (Jerusalem & Pekrun, 1999). Enjoyment of learning refers to an affective status of pleasure (Kuppens, 2008) or an emotion about how an individual feels (Hartley, 2006). Furthermore, enjoyment was classified as a state and as a trait (Goetz, Hall, Frenzel, & Pekrun, 2006). As a state, enjoyment refers to an individual’s current enjoyment of a specific activity; but as a trait, enjoyment refers to an individual’s retrospective view of personal cumulative experiences of enjoying a learning activity. Experiencing the enjoyment of learning would serve as a driving force for self-learning (Jerusalem & Pekrun, 1999; Laukenmann et al., 2003).

Burns, O’Connor, and Stocklmayer (2003) proposed that interest and enjoyment are two important aspects of evaluating the outcomes of science communication.
Hence, the assessment of these two emotional factors was a central consideration in exploring the learning effects of using comics and texts to enhance adults’ understanding of and attitudes towards nanotechnology and their perceptions of learning science.

**Methodology**

A mixed-methods quasi-experimental design was used to develop and evaluate two forms of science communications about nanotechnology. This involved developing a text booklet and a comic book with similar content and then evaluating these products with volunteer adult groups using a pretest, posttest, questionnaire, and interview.

*Development of a Text Booklet and a Comic Book*

The aim of the nanotechnology learning materials (i.e. the text booklet and the comic book in this study) was to improve laypeople’s functional nano-literacy, defined as an individual being able to use the accepted understanding of nano ideas and meaningfully discuss a limited range of nano phenomena (Lin, Lin, et al., 2013). First, a 10-page, 5-theme informational text (words only) booklet including six big ideas of nanotechnology was developed. The five themes were (a) introduction to nanotechnology, (b) the lotus effect\(^1\) and its application, (c) the biological compass\(^2\) and its application, (d) nano photo-catalysts\(^3\), and (e) possible risks of nanotechnology. The text booklet was designed to include suitable examples and address common questions that readers may have, thus making it more concrete, relevant, and understandable.

The comic book’s script was based on the contents of the text booklet that were used to create eight stories for developing similar pages in each story. The scientific information presented in the text booklet and the comics was the same; however, the presentation of information in the text booklet was out of context, and the storylines in the comics involved everyday life context. Hence, each story was deliberately designed to include attractive scientific phenomena and humorous dialogue discussing and explaining science-related issues. The text and comic scripts were reviewed by three scientists in nanotechnology based on three criteria: (a) correctness of content knowledge, (b) comprehensibility of description for the public, and (c) inclusion of the major concepts that the public should know about nanotechnology. Moreover, in order to explore adults’ perceptions of learning technology via text and comics, 13 adults (7 males, 6 females) ranging from 18 to 65 years old were invited to read the text passages and the comics for one topic (i.e. the biological compass and its application), then they were interviewed using a semi-structured protocol. The pilot test participants’ learning perceptions (i.e. interest and enjoyment) of using the comics were higher than that of those using the text. Reviewers’ and pilot test participants’ responses were considered in revising the text and the comics. Finally, a 109-page comic book was illustrated by a comic illustrator and reviewed by the authors. The development of the comic book emphasised correct external visual
representations and humorous drawings (see Appendix 1 for one-page example from the comic book).

**Research Design and Instruments**

This study used three instruments as pretests and posttests of the experimental (comic) and comparison (text) groups: the PKNT test, the PANT questionnaire, and the Public Emotional Perceptions of Learning Science (PEPLS) questionnaire. The first two instruments have been developed and validated in previous studies (Lin, Lin, et al., 2013); the PEPLS questionnaire was developed and validated in this study. In addition, seven short-answer questions accompanied the instruments in the posttest to investigate participants’ emotional perceptions of learning nanotechnology, their learning experience of using their assigned media, and their ideas for the strength and weakness of the media. Moreover, in order to enhance the meaning of the quantitative data, the first author used a 7-question semi-structured protocol lasting 10 minutes to interview a subsample of the participants after the posttest. Interviewees were selected for a telephone interview from the pool of voluntary participants who were recruited in the pretest questionnaires based on the diversity of participants (e.g. gender, education, age, and location). Ten participants in each group were interviewed.

**Public knowledge of nanotechnology.** The PKNT test contains 26 multiple-choice items and was used to assess public knowledge of six major concepts, 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 STS (4 items). The validity and reliability of the PKNT were established in an earlier study (Lin, Lin, et al., 2013). Overall KR-20 reliability of the PKNT was 0.91 for the validation sample. For the current pretest and posttest, the KR-20 reliabilities were 0.86 and 0.84, respectively.

**Public attitudes towards nanotechnology.** The PANT questionnaire contains 4-point Likert-scale items divided into 2 subscales with 10 items in the subscale of trust (e.g. When the government develops nanotechnology, do you trust that it will protect public benefits and health?) and another 10 items in the subscale of perception of benefits and risks (e.g. Nanotechnology provides people with newer and better ways to cure or examine their diseases.). The trust subscale was used to assess public trust in government agencies, the industrial sector, and scientists in managing the development of nanotechnology. The perception of benefits and risks subscale was used to measure public awareness of the potential benefits of nanotechnology. The validity and internal consistency (Cronbach’s $\alpha = 0.70$) were judged to be reasonable for this type of research in a previous study (Lin, Lin, et al., 2013). When the internal consistency was explored for the current pretest and posttest responses, the Cronbach’s $\alpha$ were 0.75 and 0.78, respectively.
Public emotional perceptions of learning science. The PEPLS questionnaire was developed and used to investigate the effect of different learning materials on the participants’ emotional perceptions of learning science. The perceptions were focused on two subscales: enjoyment (e.g. I generally have fun when I am learning science.) and interest (e.g. I am interested in science-related activities.). Each subscale contains six 4-point Likert-scale items where higher numbers designate higher levels of enjoyment or interest. The development of PEPLS was guided by (a) extraction and modification of items from previous studies such as the Student Perception of Learning Science questionnaire (Lin, Hong, et al., 2013) and large-scale international assessments such as the PISA (Organisation for Economic Co-Operation and Development, 2006), and (b) literature reviews related to public emotional perceptions of learning science such as those of Falk et al. (2007). Three science education researchers were asked to judge if each specified item assessed enjoyment or interest to explore content validity. Further validation of the PEPLS involved a principal component analysis with varimax rotation that was applied to the responses of 344 adults in the pilot test. The Kaiser–Meyer–Olkin value of 0.94 and significant value of Bartlett’s test revealed that factor analysis could be conducted for the 12 items. Since the factor loadings of the original 12 items were above 0.60, all items were retained in the questionnaire (Reise, Waller, & Comrey, 2000). Two factors were defined by the factor analysis; the construct dimension was anchored by the subscale of enjoyment with factor loadings ranging from 0.87 to 0.79 and by the subscale of interest with factor loadings ranging from 0.87 to 0.67. A total of 66.5% variance was explained by the two factors. The Cronbach’s α for the PEPLS was 0.94 in the pilot test. When it was conducted in the current pretest and posttest, overall Cronbach’s α values were 0.94 and 0.92, respectively. The Cronbach’s α values of the two subscales were 0.92 and 0.86 in the pretest and 0.88 and 0.88 in the posttest.

Participants and Data Collection

The participants involved in this study were citizens aged 20–65 years in two administrative regions of central Taiwan. The stratified sampling method was used to ensure that the sampled data were proportional to the size of the general population. According to the 2005–2006 Taiwan social change survey, 358 districts in Taiwan were clustered into seven strata, based on sociodemographic variables including age, education, industrial population, and personal income (Hou, Tu, Liao, Hung, & Chang, 2008). Districts in Tai-chung and Chang-hwa were sampled systematically from each stratum and all eligible districts with probabilities that were proportional to a measure of size. Once districts were selected for the sample, the local district administrators were visited; the purpose of the study and the concern of equivalent sampling (e.g. gender, education, and age) were explained to them. The administrators then invited their local citizens through explaining the study purpose and sending a pretest package that requested they complete the personal background information, willingness to be interviewed, PKNT, PANT, and PEPLS. The two purposes of the
pretest were the confirmation of participants and the assessment of participants’ existing knowledge of and attitudes towards nanotechnology and existing emotional perceptions of learning science. With the administrators’ assistance, the expected number of eligible citizens, which was proportional to its number of citizens, was recruited to participate in this study. Of the 350 citizens invited to participate, 303 people returned the pretest questionnaires. After the deletion of volunteers who did not fit the qualifications or provide contact addresses, the remaining citizens were randomly assigned to the text group or the comic group. Consequently, there were 291 participants (text group = 151, comic group = 140).

The learning material (i.e. a text booklet or a comic book) was mailed to each participant. They were encouraged to finish their reading in two weeks and to keep track of the time and dates of their commitment. Finally, a posttest package similar to the pretest was mailed to the 291 participants. In order to investigate the participants’ learning interest and preference for using different communication media, the posttest package containing the three instruments also contained seven short-answer questions. With the help of follow-up telephone calls and email reminders, 200 out of 291 participants’ posttest packages were received, giving a satisfactory return rate of 69%. To enhance the trustworthiness of the data, responses that presented incomplete information, identical fill-in in one subscale, or little learning track were judged to be questionable data. After the deletion of these data, the 194 acceptable responses for participants (text group = 97, comic group = 97) were analysed.

Of these 194 participants, 55% were male and 74% were non-science majors in their final education (e.g. senior high school and university). Their educational backgrounds were junior high school (15%), senior high school (32%), university (42%), and graduate school (11%). Their age distribution was 21–29 (22%), 30–39 (21%), 40–49 (26%), 50–59 (18%), and 60–65 (14%) years.

**Data Analysis**

Paired *t*-tests examined the effect of the two science communication media on public knowledge of and attitudes towards nanotechnology and on emotional perceptions of learning science. In order to examine the media effects, the analysis of covariance (ANCOVA) was used to analyse the data collected from the pretests and posttests from the two groups. The qualitative data were coded and classified for descriptive statistics. Furthermore, the codes with higher frequency were used to generate descriptive categories.

**Results**

*Is PKNT Improved by the Comic Book or the Text Booklet? Are Their Effects Different?*

Table 1 provides the PKNT pretest and posttest mean scores, standard deviations, and *t*-value of the participants’ knowledge of nanotechnology for the text and
comic groups. The results indicate that both groups made significant \((p < .001)\) pretest–posttest gains in their knowledge of nanotechnology through reading the text booklet or the comic book \((t_{text} = 13.75, t_{comic} = 16.60)\).

The ANCOVA using the pretest means as the covariate to adjust for the two groups’ initial difference revealed that there was no significant main effect for the two groups in PKNT \((F = 0.166, p = .684)\). The results of the ANCOVA and paired \(t\)-test revealed that both media had similar effects on improving PKNT.

**Are PANT Changed by the Comic Book or the Text Booklet? Are Their Impacts Different?**

The paired \(t\)-test results comparing the PANT pretest and posttest scores and subscale scores for the text and comic groups are shown in Table 2. After being involved in learning about nanotechnology, the two groups’ attitudes towards nanotechnology gains were significant \((p < .05)\) and positive \((t_{text} = 2.45, t_{comic} = 2.29)\). Although the scores of the four subscales in PANT increased after learning, only the scores of trust in scientists significantly improved for the two groups. The participants’ interview data revealed that their understanding of nanotechnology content based on

<table>
<thead>
<tr>
<th>Group ((n))</th>
<th>Pretest M (SD)</th>
<th>Posttest M (SD)</th>
<th>(t)</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Text (97)</td>
<td>7.15 (5.34)</td>
<td>15.95 (5.66)</td>
<td>13.75****</td>
<td>1.60</td>
</tr>
<tr>
<td>Comics (97)</td>
<td>6.70 (4.89)</td>
<td>15.49 (4.68)</td>
<td>16.60****</td>
<td>1.84</td>
</tr>
</tbody>
</table>

****\(p < .001\).

<table>
<thead>
<tr>
<th>Group</th>
<th>Attitude</th>
<th>(n)</th>
<th>Pretest M (SD)</th>
<th>Posttest M (SD)</th>
<th>(t)</th>
<th>Effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Text</td>
<td>Trust (G + I)</td>
<td>97</td>
<td>11.64 (2.49)</td>
<td>12.09 (2.26)</td>
<td>1.76</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>Trust (S)</td>
<td>97</td>
<td>12.27 (2.10)</td>
<td>12.97 (1.94)</td>
<td>3.30***</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>Benefit</td>
<td>96</td>
<td>14.89 (1.69)</td>
<td>14.89 (1.69)</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Risk</td>
<td>94</td>
<td>14.71 (1.76)</td>
<td>14.96 (1.73)</td>
<td>1.24</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>94</td>
<td>53.50 (4.49)</td>
<td>54.79 (4.67)</td>
<td>2.45*</td>
<td>0.28</td>
</tr>
<tr>
<td>Comic</td>
<td>Trust (G + I)</td>
<td>94</td>
<td>11.99 (2.37)</td>
<td>12.21 (2.29)</td>
<td>0.90</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Trust (S)</td>
<td>94</td>
<td>12.44 (2.16)</td>
<td>13.01 (2.08)</td>
<td>2.41*</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>Benefit</td>
<td>95</td>
<td>14.44 (1.75)</td>
<td>14.75 (1.34)</td>
<td>1.76</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Risk</td>
<td>94</td>
<td>14.60 (1.75)</td>
<td>14.83 (1.55)</td>
<td>1.45</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>92</td>
<td>53.49 (5.08)</td>
<td>54.68 (4.46)</td>
<td>2.29*</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Notes: Trust (S) = trust in scientists; Trust (G + I) = trust in government and industry.

\(*p < .05.\)

\(**p < .01.\)

\(***p < .005.\)
the two media led them to have confidence in judging scientists’ work and, thus, to increase their trust in scientists. For example, two text readers noted,

Because I have an understanding of the basic knowledge of nanotechnology, I can judge whether their reports [are true or not] based on my knowledge, rather than based on the title of ‘nanotechnology’. Therefore, my trust in scientists increased after learning about nanotechnology. (ID 10410_T)

If scientists’ research reports are based on experiments, I will trust them. (ID 10101_T)

ANCOVAs were conducted to examine whether there were any significant main effects in overall and subscale scores of PANT between these two groups. The results revealed that there was no significant difference in overall PANT between the two groups ($F = 0.026, p = .872$). Moreover, there was no significant difference in each subscale of PANT between the two groups. The participants’ attitudes towards nanotechnology appear to be influenced by their similar improved understanding of science and knowledge related to nanotechnology.

In order to examine the relationship between the change in PKNT and the change in their respective attitudes, a correlation analysis was conducted. The result indicated small but significant ($r = 0.134, p = .034$) correlations between the pretest–posttest PKNT gain scores and the pretest–posttest PANT gain scores. This result indicates that the participants’ improvement in their understanding of nanotechnology is associated with their attitudes becoming more positive.

Are PEPLS Changed by the Comic Book or the Text Booklet? Are Their Impacts Different?

The means and standard deviations of the two groups’ pretest and posttest PEPLS scores are shown in Table 3. The results of the paired $t$-test revealed that the mean scores of interest for the two groups did not significantly increase after learning. However, it is noted that the mean scores of interest for the comic group increased while those for the text group decreased after learning. The participants’ responses to the short-answer questions indicated that more comic readers (83%) were interested in using their assigned media to learn more about nanotechnology than the text readers (71%). The main reason reported by the comic readers was that the comics presenting living stories that narrated laypeople’s daily life made science

<table>
<thead>
<tr>
<th>Group</th>
<th>Perception</th>
<th>$n$</th>
<th>Pretest $M$ (SD)</th>
<th>Posttest $M$ (SD)</th>
<th>$t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Text</td>
<td>Enjoyment</td>
<td>97</td>
<td>17.54 (2.97)</td>
<td>17.42 (2.59)</td>
<td>−0.43</td>
</tr>
<tr>
<td></td>
<td>Interest</td>
<td>97</td>
<td>16.65 (2.94)</td>
<td>16.35 (2.83)</td>
<td>−1.16</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>97</td>
<td>34.19 (5.64)</td>
<td>33.77 (5.11)</td>
<td>−0.87</td>
</tr>
<tr>
<td>Comic</td>
<td>Enjoyment</td>
<td>97</td>
<td>17.21 (2.63)</td>
<td>17.27 (1.96)</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Interest</td>
<td>97</td>
<td>16.35 (2.70)</td>
<td>16.47 (2.27)</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>97</td>
<td>33.56 (5.01)</td>
<td>33.74 (3.95)</td>
<td>0.41</td>
</tr>
</tbody>
</table>
more understandable and attractive for learning about nanotechnology than normal text does. For example, they noted:

The story, which occurred in an everyday context, made me empathise [with the character] and promoted my understanding of the science content. (ID 31137_C)
Comics can induce my interest in learning, because reading technology information as text, as is usual, is boring. (ID 31149_C)
Comics are lively and easy to understand. (ID 31121_C)
The comic book is so interesting that I can read it repeatedly. (ID 31139_C)

The comic readers’ responses indicated that the features that attracted them to engage in learning are the contextualised, novel, and understandable aspect of the comics. On the contrary, the text booklets not only did not enhance the readers’ mean scores of interest, but also in fact decreased their interest. Some text readers responded that

The text booklet is difficult to understand because there are many professional terms and no pictures for explanation. It is boring. (ID 31134_T)
It takes me a lot of time to study the content. (ID 41319_T)

In fact, the quantity of professional terms was controlled; it was the same in the text booklet and the comic book. Probably, the conversational words occurring in an everyday context of the comics connected with their experience and mediated terminology with their existing science knowledge background. However, text that does not connect with their knowledge background highlights the existence of difficult and uncommon professional terms and decreases their learning interest.

The ANCOVA conducted to compare the posttest mean scores of interest for the two groups—their pretest mean scores were used as the covariate to adjust their initial difference before intervention—revealed that there was no significant difference between the adjusted mean scores ($F = 0.842, p = .360$). The treatment difference did not appear to influence the learning interest for using the text booklet and the comic book.

The paired $t$-test results for the participants’ enjoyment in science learning (Table 3) did not significantly increase through using either the text booklet or the comic book ($t_{text} = 0.43$, $t_{comic} = 0.25$). The responses to the short-answer questions revealed that more than 80% of the participants (text group = 82%, comic group = 85%) had positive emotional perceptions (i.e. enjoyment, excitement, and liking) of learning about nanotechnology with both the text and the comic book. The responses indicated that obtaining new knowledge (e.g. novelty, benefit, and risk) and application of nanotechnology not only made them happy but also satisfied their curiosity (ID-10118-T, ID-41304-T, ID-30120-C, and ID-31318-C). Thus, we propose that the understandable and contemporary contents presented in both media might be the main factors bringing participants similar enjoyment of science learning.

Discussion

Some researchers have assumed that the use of comics is an exciting way of communicating science (Tatalovic, 2009; Weitkamp & Burnet, 2007), but only few studies
have actually examined the effects of science communication via comics. The empirical significance of this study is that, to the best of our knowledge, this may be the first study to investigate systematically the impact of science comics on the public communication about an emerging technology. The results showed that the comic book is as effective as traditional text only for science communication, not only in terms of improvement in knowledge and stimulation of learning interest but also in generating more positive attitudes towards the topic. Public understanding of nanotechnology appears to make the participants more confident in judging advertisements for nano-products and scientists’ reports. Thus, the improvement in PKNT is essential to ensure that people develop more positive attitudes, which hopefully will allow them to make informed decisions and take sustainable actions as engaged citizens.

It is noted that comic readers’ learning interest and enjoyment increased after learning, while those of the text readers decreased. Similar to the instruments for assessing interest and enjoyment in previous studies (Lin, Hong, et al., 2013; Lin, Lawrenz, et al., 2013), the PEPLS questionnaire was designed to assess personal interest and the trait emotion of enjoyment by soliciting adults’ interest and enjoyment in science-related contents and activities. It is not easy for a one-shot treatment (e.g. reading a comic book) to enhance learners’ interest and enjoyment significantly on PEPLS. The short-answer questions assessed the participants’ short-term situational interest and current enjoyment triggered by specific features of the media. More comic readers expressed their interest in learning nanotechnology via comics than text readers who expressed interest in learning via text. The attractive features of the comic book for laypeople were understandability, liveliness, contextual nature, and aspects of novels. In general, comics have the power to capture children’s interest and are used to improve children’s engagement in learning (Weitkamp & Burnet, 2007; Worthy, Moorman, & Turner, 1999). Our results revealed that the power of comics also works well with adults learning science. Collectively, the contrary emotional outcomes between the text and comic groups imply that science comics can serve as an effective medium of science communication, especially for developing learners’ interest through cumulative experiences of enjoying learning science by reading comics.

Tatalovic (2009) cautioned that if science is made to be fun by the use of impressive artwork and humorous dialogue in comics, the artwork and plot of dialogue might discount the effect of conveying scientific ideas. However, the learning effect (i.e. improvement in knowledge) of the comics in this study was as good as that of the text. It is, therefore, worth addressing the useful factor in reading the comic book. Based on the comic readers’ responses regarding the advantages of learning via comics, we found that the dialogue in the comic book was able to transform rigid science into soft/simple words to make the science easy to learn. In other words, the structure and linkage of speech bubbles or the language to specific characters or events in the comic made the logical connections more explicit for the readers and improved their understanding of science. Thus, conversational language in the comic book was seen as soft/simple words, but the decontextualised scientific language in the text booklet was seen as rigid science. Newton (2002) argued that stories can provide context to a problem or explanation to help children understand
science concepts. We believe that conversational language in comics makes science accessible and understandable for both children and adults.

One of the most worthwhile results in this study is the finding that there was no statistically significant difference in the PKNT and PANT scores of the comic and text groups. As previously mentioned, the majority of the participants reported that the contents of the text/comic were understandable. The first possible reason was that the two media, which were developed based on the principles of adult learning, contained common questions and provided comprehensive content even though they used different representations. Jarvis (2004) suggested that the content for adult learning should be designed ‘relevant to the experience/problem that created the felt need to learn’ (p. 144). Thus, the four design principles used to develop science materials—generating questions or issues related to their experience inducing their motivation, providing explanations with scientific language that junior high students can understand, developing text with concept structure, and identifying the main ideas with titles and bold words—were used to produce the text booklet. The main body of the comic script is dialogue/narrative that was developed based on the first three principles used for developing the text booklet. Another three principles—integrating an element of humour, combining visual and verbal representations, and maintaining visual images more than words—were added to develop the comic book. Hock and Mellard (2005) argued that most of these design principles were beneficial to using reading comprehension strategies. For example, explicitly indicating main ideas and fewer text pages help readers to learn the main ideas by easy searching and repeated reading. Meanwhile, conversational language and humour in comics help learners engage in reading more easily and for longer periods of time. Therefore, based on the results of this study, we believe that conveying comprehensive content is the main reason for the similar impact of the two media.

The second possible reason that may have caused the similarity in the knowledge and attitudes of the two groups was these adults’ ability to engage in abstract thought. Unlike children, adults are able to think abstractly and construct mental images through understanding the meaning of the text and connecting these meanings with their prior knowledge and experience. Even though a text generally lacks visual representation, a well-designed text can still help adults to visualise ideas and to learn science.

Since previous research in the area of science comics is limited, this study can be seen as a pioneering study assessing the effects of science comics on public knowledge, attitudes, and learning perceptions. For public science education, using a medium that will capture laypeople’s interest in learning science is especially critical. Further studies exploring the impact of different comic forms and popular media (e.g. animation and TV cartoons) for a variety of learners are recommended. The results of the posttest PKNT scores showed that most of the participants could understand more than 60% of the nanotechnology knowledge after learning with either medium. In addition, most of the readers surveyed had an education background of senior high school. In order to provide the general public with a full understanding and appreciation of nanotechnology, content including the nine big ideas of nanotechnology is suggested as a foundation for developing such an information medium.
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Notes

1. The lotus effect refers to the phenomenon whereby water is repelled from a hydrophobic surface (e.g. a lotus plant leaf) to form water drops.
2. Biological compass refers to certain magnetic materials that exist in the bodies of some animals and give these animals the ability to orient themselves and migrate. The ability of orientation may be induced by these animals' perception of the magnetic field on earth.
3. Nano photo-catalyst refers to the nano-scale materials that have the ability of a catalyst to accelerate a photoreaction. Titanium dioxide (TiO₂) is one of the most commonly used photo-catalyst materials.

References


Appendix 1. One-Page Example of ‘Knowing Nanotechnology via Comics’—Cited from the unit of target therapy. The original comic was in Chinese