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Proceedings of the Annual Meeting of the Cognitive Science Society

Title
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Permalink
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Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 28(28)

ISSN
1069-7977

Authors
Campbell, Gwendolyn E.
Chin, Simone L.

Publication Date
2006

Peer reviewed

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The Fit of the Implicit Cognition Paradigm to Science Education Research: An Exploratory Analysis

Gwendolyn E. Campbell (Gwendolyn.Campbell@navy.mil)
NAVAIR Orlando TSD, Code 4651, 12350 Research Parkway
Orlando, FL 32826-3275

Simone L. Chin (Simone.Chin.CTR@navy.mil)
Kaegan Corporation 12000 Research Parkway, Suite 164
Orlando, FL 32826-3275

Abstract

In this paper we propose that cross-fertilization between science education research and implicit cognition research could be mutually beneficial. In particular, we detail hypotheses about the nature and prevalence of misconceptions in different scientific domains that could be generated from an implicit cognition perspective and describe methodological guidance that could be derived from this same perspective. Next, we present our study, which involved collecting data from 80 participants who completed a pre-test, a computer-based lesson, hands-on activities and a post-test, after being randomly assigned to a scientific domain (classical mechanics or circuits) and teaching technique (traditional or conceptual change). Finally, we show that our data support the theoretically driven hypotheses and that the methodological techniques increased the power and sensitivity of our analyses, lending credence to our claim that more interaction between these two communities could be fruitful.

Introduction

For decades, researchers in the field of science education have been working to characterize both naïve and expert scientific knowledge and reasoning, and trying to identify instructional techniques that facilitate the development of scientific expertise. As within any research community, a paradigm, complete with constructs, theories and methods has emerged over time, and this paradigm simultaneously facilitates some aspects of investigation and limits others.

Some of the most robust findings to emerge from this body of research include: (a) people of all ages have conceptual understandings of the physical world that are considered inaccurate by the scientific community (e.g., Champagne, Klopfer & Anderson, 1980; Clement, 1982; diSessa, 1982; McDermott, 1984; Nakhleh, 1992; Nussbaum, 1985; Shipstone, 1985), (b) these "naïve" or "intuitive" conceptions appear to form "unconsciously" through a person's experiences interacting with the real world (Clement, 1982; diSessa, 1982; Eylon & Linn, 1988; Linn, 1986), and (c) these conceptions are highly resistant to change in a traditional classroom environment (Champagne, Klopfer & Anderson, 1980; Eylon & Linn, 1988; Linn, 1986; McDermott, 1984).

Despite the strong resemblance between this characterization of naïve or intuitive scientific knowledge (or scientific misconceptions) and the construct of implicit knowledge in cognitive science, there appears to be limited cross-fertilization between the two fields (for an exception, see Kozhevnikov & Hegarty, 2001). The goal of this paper is to demonstrate that science education research could benefit by the incorporation of theory and methods from the implicit cognition paradigm. We hope to support this claim by providing an illustration through the context of a prototypical science education experiment.

The implicit cognition paradigm

At the core of any paradigm is a set of phenomena believed to be meaningful, worthy of study and in need of explanation. Research in implicit cognition focuses on the many instances in which some aspect of a person's behavior demonstrates predictable regularities, and yet the person is either unaware of or unable to articulate the guiding forces that produced this behavior. For example, most native speakers of American English can easily distinguish between sentences in which the adjectives are in the "right" order ("The cute, little, blonde-haired boy…") and sentences in which the adjectives are not ("The blond-haired, little, cute boy…"). Few, however, can produce the complex set of more than a dozen linguistic rules that dictate "correct" adjective order in this language. Dissociations between behavior and conscious knowledge such as this are not restricted to normal populations, but are also found in populations with neurological disorders such as amnesia and prosopagnosia. For example, people suffering from prosopagnosia, the inability to recognize faces, show a galvanic skin response to photographs of familiar faces, even when they cannot pick the name of the familiar person from a set of choices at a level better than chance (Bauer, 1984).

While there are many areas of active research and contention within the community, there is a generally accepted belief in 2 separate cognitive systems associated with learning, representation and/or processing. The typical characterizations of the system labeled "implicit" include perceptually learned, rapid processing capacity, best represented in a connectionist framework, and cognitively impenetrable. In contrast, the typical characterizations of the system labeled "explicit" include slow and serial processing, under volitional control, best represented

symbolically and available for introspective study and verbal report.

Theory-based contributions

Our first contention is that theories about the nature and development of implicit and explicit knowledge will help address many of the common findings and problems in science education. For example, Kozhevnikov and Hegarty (2001) show how adopting a theoretical perspective from the study of implicit cognition can help to determine (a) the circumstances under which intuitive scientific theories are likely to be correct or incorrect, as well as (b) the contextual and/or environmental variables that are likely to dictate whether a person's response will be most strongly influenced by explicitly learned and officially sanctioned scientific knowledge or an intuitive theory.

Similarly, a theoretical perspective of implicit learning is able to account for the relative prevalence and strength of intuitive conceptions across different scientific domains, by referencing the extent to which opportunities for observing patterns of regularities in each domain are present in a person's natural environment. To illustrate this, we compare misconception data from two well-studied scientific domains, classical mechanics and circuits. In both domains, a number of common misconceptions have been identified in previous research literature[1] and measurement instruments have been developed (e.g., Halloun & Hestenes, 1985; Sokoloff, 1996). However, an implicit learning theoretical perspective would suggest that humans are more likely to learn implicitly in the area of classical mechanics than in the domain of circuits, because our natural environment provides a wider variety of opportunities to experience regularities across the many facets of object motion (e.g., lifting, pushing, pulling, carrying, dropping, and throwing objects of all shapes and sizes) than in the area of circuits, in which most people typically have limited and impoverished experiences (e.g., turning on and off electronic devices, replacing batteries and fuses). Thus, in the following study, we test the hypotheses that a comparison of the prevalence and nature of common misconceptions in classical mechanics and circuits will show that (a) the classical mechanics misconceptions are more prevalent and (b) the circuits misconceptions are held at a more explicit level.

The potential contribution of this theoretical perspective goes beyond explaining how and why intuitive misconceptions are formed, and can also provide guidance regarding instructional techniques that are likely to overcome these misconceptions. For example, consider an instructional technique commonly promoted in the science education literature: the conceptual change method. This teaching approach is often credited to Posner and colleagues (Posner, Strike, Hewson & Gertzog, 1982) who identified a series of conditions that they posited must be met before a student would be willing to replace an existing conceptualization with a new one. Those conditions are: (a) the new conceptualization must be intelligible to the student, (b) the new conceptualization must be plausible to the student, (c) the student must experience significant dissatisfaction with his/her current conceptualization, and (d) the student must be convinced of the fruitfulness of the new conceptualization, especially in regards to the area in which the dissatisfaction with the original conceptualization has occurred. Based on this perspective, the conceptual change instructional technique attempts to induce dissatisfaction by eliciting the current conceptualization and then having the student complete one or more activities designed to demonstrate the failure of that perspective and the fruitfulness of an alternative conceptualization.

Of course, many science classes include laboratory activities that demonstrate outcomes and provide the accepted explanations for those outcomes. The presumed crux of the conceptual change method of instruction is the induction of dissonance through the elicitation of seemingly relevant but inaccurate intuitive conceptions before beginning an activity. In other words, the conceptual change instructional technique is hypothesized to be effective at overcoming implicit but inaccurate knowledge in scientific domains because it includes steps for making the implicit knowledge explicit before attempting to counter that knowledge.

Interestingly, research in child development and learning conducted within the implicit cognition paradigm thinks about the transition from implicit to explicit knowledge differently. Clements, Rustin and McCallum (2000) studied the development, with instruction (in the form of feedback and explanation), of children's understanding of the concept of "false belief". Their conclusion was that this learning proceeded predictably through a multi-stage process. First, children implicitly picked up on regularities in the environment that were consistent with the false belief concept. Only after this implicit learning had taken place, did children appear to be ready to learn from the explicit feedback provided, and bring their explicit answers in line with the false belief concept. Finally, it was only after their explicit answers were accurate that they appeared able to learn from the explicit explanations that were provided during training. Thus, this theoretical perspective might well predict that an explicit attack on misconceptions is only likely to be successful after a change has taken place at the implicit level, bringing implicit knowledge more closely into alignment with accepted scientific knowledge, and that it is the exposure to experiences with a different set of regularities than those observed in every day life that promotes the necessary implicit learning.

These two different perspectives, 'implicit knowledge can be affected if it is forced into explicitness and addressed

[1] For example, research in classical mechanics has shown that many people believe that when two objects collide, the object with the largest mass exerts the largest force. Similarly, research in circuits has shown that many people believe that a battery provides a source of current that is progressively weakened as it travels through each light bulb in a circuit.

directly' versus 'explicit intervention will only be effective after implicit changes have occurred', yield different predictions about the effectiveness of the conceptual change technique. Specifically, science education researchers are likely to hypothesize that the conceptual change technique should work in all domains, while researchers applying an implicit cognition theoretical perspective are likely to hypothesize that the method is not likely to be effective at changing misconceptions that are held implicitly. If, in fact, our previously stated hypotheses (that misconceptions will be more prevalent and more implicitly held in classical mechanics than in circuits) are supported, then our current study will also provide the opportunity for an exploratory investigation contrasting these two predictions about the effectiveness of the conceptual change technique.

Method-based contributions

In addition to providing a theoretical framework to predict and explain findings in science education research, the implicit cognition paradigm may also provide new operational definitions, experimental designs and assessment techniques.

Consider assessment techniques. It is almost always the case in science education research that "direct" tests are used to assess knowledge and learning (for an exception, see Pittinger, 1991). In the implicit cognition community, "indirect" tests are believed to be best at capturing implicit knowledge, while direct tests are thought to mostly reflect explicit knowledge (e.g., Cleeremans, Destrebecqz & Boyer, 1998; Dienes & Perner, 1999; Kozhevnikov & Hegarty, 2001). So, adopting this paradigm immediately expands the pool of available assessment techniques for researchers in the science education field.

Of course, many implicit cognition researchers also acknowledge that implicit knowledge may "bleed over" into answers on direct tests and explicit knowledge may influence performance on indirect tests (Cleeremans, et al., 1998; Dienes & Perner, 1999). As an alternative, Dienes and Perner (1999) propose that explicitness be treated as a graded characteristic (rather than dichotomous) and suggest that different types (or levels) of responding on a direct (multiple-choice) test may indicate knowledge held at different levels of explicitness (see Table 2, p. 747). We believe that this assessment approach provides for a fine-grained examination of science education study results, potentially providing more insight into the impact, capabilities and limitations of various instructional techniques than the standard change score (# correct on post-test minus # correct on pre-test) approach. Thus, we adopted this methodological approach in our current study, in order to demonstrate its usefulness to the science education research community.

Method

Participants

A total of 80 undergraduate students from a Florida university participated in the experiment. There were 26 males and 54 females, and the average age of the participants was 21 years (SD=4.0). Students received extra credit points, payment, or some combination of the two in exchange for their participation.

Design

There were two independent, between-subjects variables: domain (classical mechanics versus circuits) and type of instruction (traditional versus conceptual change). For logistical reasons, all of the participants in the D. C. circuit's condition were run first. However, within each domain, participants were randomly assigned to an instructional condition.

Materials

Toolbook© was used to create two self-paced, computer-based lessons. The lesson on circuits covered fundamental topics such as voltage, current, resistance and power, Ohm's Law, conservation of current, and series and parallel circuit configurations. The lesson on classical mechanics covered Newton's first three laws of motion.

For each topic, pre- and post- tests were developed to assess a participant's knowledge of the material covered in the lesson. The tests consisted of multiple-choice questions, with distracter items carefully written to reflect common misconceptions in each domain (as identified in previous literature). The tests were implemented in Toolbook© as well, so that they were computer-administered. In addition to selecting an answer from among the available choices, participants were prompted to explain their selection by typing into a text box after most of the questions.

Finally, hands-on activities and associated worksheets were developed for each domain. Across both domains, the activities were designed to address common misconceptions. The four circuits activities involved building series and parallel circuits with batteries, small light bulbs, switches and alligator clips and measuring voltage with a voltmeter and current with a compass. The two classical mechanics activities involved experimenting with object motion on an air hockey table and comparing the speed of different designs of wind-sail cars.

Three handouts were created for each activity. First was the primary activity worksheet, which provided detailed written instructions for conducting the activity, illustrations when appropriate, and places to record the outcomes of the various manipulations being conducted. Second was the explanation sheet, which described the outcomes of the activity (when done correctly) and explained those outcomes in terms of the concepts presented in the lesson. All participants received these worksheets, regardless of condition. Finally, a prediction worksheet was also created

for each activity. This brief worksheet asked the participant to predict the outcome of the activity before conducting it and explain the rationale behind the prediction. Only participants in the conceptual change condition received the prediction worksheets for the activities.

Procedure

After listening to the experimenter read a scripted introduction and completing the informed consent paperwork, a participant completed a series of surveys, including a brief demographic questionnaire, the NEO five-factor personality inventory (form S), and measures of locus of control and goal orientation. Next, the participant took the computer-based pre-test. Following this test and a short break, the participant worked through the computer-based lesson on the selected domain (classical mechanics or circuits).

The hands-on activities were introduced after the completion of the computer-based lesson and another short break. In the traditional condition, a participant followed the instructions on an activity worksheet to complete the activity, recorded the results of the activity, and then read an explanation sheet that tied the activity outcome to the concepts presented in the lesson.

In the conceptual change condition, there were two modifications to this procedure. First, after being introduced to the planned activity, the participant was asked to predict the outcome of the activity and record both the prediction and a justification for that prediction on a separate worksheet. Second, after completing the activity but before being provided with the explanation sheet, the participant was asked to record both whether or not the outcome was consistent with the prediction and an explanation if the two were not consistent.

Finally, after the last scheduled break, the participant took the computer-based post-test, completed a reaction questionnaire, and was debriefed. Regardless of the domain or instructional condition, most participants were able to complete this procedure in approximately 3 hours.

Results

Pre- and post-test assessment

A scoring system was developed for the multiple-choice answers and explanations on the pre- and post-tests for both domains. The goal of this system was to identify which misconceptions a participant appeared to hold, and the extent to which each misconception was held explicitly. In order to accomplish this, we applied a two stage scoring system. In the first stage we focused on the multiple-choice answers selected by each participant. As described earlier, the majority of the distracters were designed to represent commonly held misconceptions in that domain. A participant was labeled as possessing the misconception if that participant selected distracters representing that misconception at least 35% of the times that they were available. (A lower cut-off corresponded too closely to selecting those distracters by random chance. A higher cut-off was deemed inappropriate, because misconceptions competed within each question, and while it is possible for a participant to hold both misconceptions, the participant was only allowed to select one distracter.)

In the second stage, we focused on the written explanations given by each participant for the majority of the questions. Each written answer was categorized on the extent to which it provided a clear explanation of the specific misconception underlying the chosen distracter. One author developed the categorization rules and trained two coders to complete this task. As in stage 1, we used a ratio to judge the extent to which a misconception was held explicitly. A misconception was said to be held explicitly if clear and appropriate explanations were provided at least 85% of the time that distracters representing a particular misconception were chosen.

To summarize, common misconceptions identified in the literature were represented in distracters repeatedly throughout the test. If a participant only selected distracters representing one misconception sporadically, we determined that the participant probably did not hold that misconception. If a participant routinely chose distracters representing a specific misconception, but was not able to consistently provide clear and appropriate explanations for these choices, then we concluded that the participant held this misconception, but at a low level of explicitness. Finally, if a participant routinely chose distracters representing a specific misconception, and consistently provided clear and appropriate explanations for these choices, then we concluded that the participant held this misconception at a highly explicit level.

Hypothesis testing

Our first hypothesis was that participants would come to the experiment with a higher prevalence of misconceptions in the mechanics domain than in the circuit's domain. Each participant was assigned a prevalence score by dividing the number of misconceptions held at pre-test by the total number of misconceptions assessed in our tests. As predicted, the average prevalence score in the mechanics domain (M = .481, SD = .222), was significantly higher than average prevalence score in the circuits domain (M = .378, SD = .131), $t(78) = 2.51$, $p = .014$.

Our second hypothesis was that, when present, circuit's misconceptions were more likely to be held explicitly than mechanics misconceptions. Each participant was assigned an explicitness score by dividing the sum of misconceptions held explicitly by the total number of misconceptions held. As predicted, the average explicitness score in the circuits domain (M = .684, SD = .327) was significantly higher than the average explicitness score in the mechanics domain (M = .456, SD = .391), $t(76) = 2.78$, $p = .007$.

Exploratory analyses

The previous analyses provide evidence that the scientific domains of mechanics and circuits differ in the extent to

which intuitive misconceptions are held at an implicit level. Recall that the science education literature proposes that the conceptual change instructional technique is an effective method for overcoming any intuitive misconception. On the other hand, an implicit cognition perspective suggests that this technique is less likely to be effective when misconceptions are held implicitly. Thus, our third set of analyses explores this contrast by assessing the effectiveness of this specialized instructional technique in each domain.

As described earlier, each misconception could be classified as (a) not held, (b) held with high explicitness or (c) held with low explicitness on each test. This produced a total of 9 possible combinations for each misconception and for each participant. Three combinations were assessed as showing improvement – a high-explicit misconception at pre-test becoming not held at post-test, a low-explicit misconception at pre-test becoming not held at post-test and a low-explicit misconception at pre-test becoming a high-explicit misconception at post-test. An improvement score was calculated for each participant by taking the ratio of misconceptions showing improvement to the total number of misconceptions held by that participant at pre- and/or post-test. (Note that misconceptions that were not held at either pre- or post-test were not included in this calculation.)

In the circuits domain, the average improvement score in the conceptual change condition (M = .754, SD = .232) was significantly higher than the average improvement score in the traditional instruction condition (M = .512, SD = .324), $t(38) = 2.69$, $p = .010$. However, in the mechanics domain, the average improvement score in the conceptual change condition (M = .531, SD = .276) was not significantly different from the average improvement score in the traditional instruction condition (M = .491, SD = .318), $t(36) = .409$, $p = .684$.

Supplemental analyses of alternative explanations

Two of our findings could be challenged with commonly acknowledged alternative explanations. First, an omnipresent concern in research comparing different instructional techniques is that two techniques often vary along two dimensions, the nature of the processing activities and the amount of time required to complete the activities. To test for this alternative explanation in our data, we compared the average amount of time spent on the activities between our conceptual change and traditional groups for the circuits domain (the only domain for which conceptual change appeared to be more effective). There was no statistically significant difference in the amount of time spent on the activities in the conceptual change condition (M = 82 minutes, SD = 22 minutes) and the traditional condition (M = 80 minutes, SD = 19 minutes), $t(38) = 0.26$, $p = 0.79$. This result increases our confidence that the improvement associated with the conceptual change condition is due to the nature of the processing activities rather than the amount of time spent working with the material.

Next, consider our interpretation of the participants' written explanations. As described earlier, the presence or absence of clear and appropriate written explanations provided in conjunction with multiple choice selections was interpreted as evidence regarding the extent to which a misconception was held explicitly. One possible alternative explanation for the variance found in this variable is some form of individual differences in our participants. The small battery of measures given to each participant at the beginning of the experiment was considered, and the "conscientiousness" score on the NEO five-factor personality inventory was selected as the most likely candidate to account for this variance. However, a correlational analysis showed no relationship between a participant's conscientiousness score and the extent to which the participant provided clear and appropriate written explanations in conjunction with his or her multiple choice selections $r(76) = .09$, $p > .05$.

Discussion

Our objective in this paper was to propose that the implicit cognition paradigm is highly appropriate for research being conducted in science education, and to illustrate, using a prototypical science education study, some of the potential benefits that could be realized if there was more cross-fertilization between these two fields.

From a theoretical perspective, we showed how a developmental theory of implicit knowledge supported an accurate prediction of the relative prevalence and nature of misconceptions in two different scientific domains. More specifically, we were able to hypothesize that common misconceptions in classical mechanics would be more prevalent and held less explicitly than common misconceptions in circuits, and, in fact, our data supported both of those hypotheses.

Beyond providing insight into the nature of scientific misconceptions, the implicit cognition paradigm also appears to have promise for generating candidate instructional techniques to overcome misconceptions. In this paper, we described how the paradigm would predict that the effectiveness of the conceptual change technique would be limited to those domains in which misconceptions were held explicitly, rather than implicitly, and, once again, our exploratory analyses were consistent with this prediction.

Methodologically, it should be pointed out that neither of our hypotheses could have been tested using the standard change score. Both hypotheses required a comparison between domains, and it would not be appropriate to compare either raw or percentage change scores on different tests from different domains. The problem with using a change score is that it isn't possible to disambiguate domain effects (e.g., the circuits group showed a larger gain score than the mechanics group because circuits is an easier topic to learn than mechanics) from test effects such as the selection and wording of individual questions (e.g., the circuits group showed a larger gain score than the

mechanics group because most of the questions in the mechanics test, but not the circuits test, focused on difficult concepts in that domain). By focusing our analyses at the level of individual misconceptions, applying the exact same criteria in each domain to determine if a misconception is held or not, and never relying on a single question to draw a conclusion, we can leverage the fact that each test was designed to cover the major misconceptions in its domain, and thus make reasonable between-domain comparisons.

In addition, the second hypothesis referred to the level of explicitness with which various misconceptions were held, and percent correct on a multiple-choice exam doesn't give any insight into that variable.

Of course, it would be inappropriate to draw strong conclusions from this particular illustration. The real point is that the implicit cognition paradigm made different predictions and brought different operational definitions and methods to the table, opening up the possibility of gaining new and different insights into the questions that the science education research community has been working on.

While we have chosen in this paper to emphasize the potential contributions of the implicit cognition paradigm to the field of science education research, the benefits of cross-fertilization between the two domains would obviously be reciprocal. At the very least, the field of science education offers a rich and challenging real world environment for implicit cognition researchers as they move beyond laboratory tasks in memory and artificial grammar learning.

This is clearly a preliminary and somewhat exploratory investigation, however we hope we have provided some insight into the potentially beneficial relationship that could be established between researchers in these two areas. We certainly plan to continue to investigate our current data set and plan future science education studies in the light of the implicit cognition paradigm.

Acknowledgments

The authors would like to thank Lisa Durrance, Cheryl Johnson, Kimberlie St. Louis and Sherry Yelland for help with the data collection and analysis, and Dr. Susan Chipman of the Office of Naval Research for sponsoring this work.

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