Observing Intellectual Need in Online Instructional Tasks

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The idea of intellectual need, which proposes that learning is the result of students wrestling with a problem that is unsolvable by their current knowledge, has been used in instructional design for many years. However, prior research has not described a way to empirically determine whether, and to what extent, students' experience intellectual need. In this paper, we present a methodology to identify students' intellectual need and also report the results of a study that investigated students' reactions to intellectual need-provoking tasks in first-semester calculus classes.

Keywords: Intellectual Need, Instructional Videos, Flipped Pedagogy

Problem solving has long been viewed as both an essential source and product of mathematical learning. However, Fuller, Rabin, and Harel (2011) characterize much of students' engagement with mathematics as "problem-free" in the sense that the mathematical "problems" students encounter can ordinarily be completed by applying skills and understandings previously developed, and thus are better characterized as "exercises." In contrast, "problem-laden" activity originates in and is sustained by students' construction of a problem in such a way that they (1) recognize their current knowledge structures as insufficient to solve the problem, and (2) construct an image of the understandings that would enable them to progress towards a solution. To address this issue, Harel (1998) proposed the *necessity principle*: "For students to learn what we intend to teach them, they must have a need for it, where 'need' refers to intellectual need" (p. 501). Although the construct of intellectual need has been widely applied in instructional design (e.g., Harel, 2013b; Koichu, 2012; Caglayan, 2015; Foster & de Villers, 2015) and analysis (e.g., Rabin, Fuller, & Harel, 2013; Zazkis & Kontorovich, 2016), prior research has not developed methods for empirically identifying students' experiences of intellectual need.

The goal of this paper is to explore the possibility of explicitly identifying students' self-reported experiences of intellectual need and to examine related factors that might be associated with these experiences. In addition, we seek to explore the relationships between students' experiences of intellectual need and their learning from instructional videos that were designed to present solutions to intellectual need-provoking [IN-P] tasks and to explicate the understandings and ways of reasoning required to construct these solutions.

Theoretical Framework

The concept of intellectual need is situated within an elaborate theoretical framework called *DNR-based instruction in mathematics* (Harel, 2008a) and is informed by two key theoretical premises: the *Knowing Premise* and the *Knowing-Knowledge Linkage Premise*. The Knowing Premise states, "Knowing is a developmental process that proceeds through a continual tension between assimilation and accommodation, directed toward a (temporary) equilibrium" (Harel, 2008b, p. 894). Relatedly, the Knowing-Knowledge Linkage Premise states, "Any piece of knowledge humans know is an outcome of their resolution of a problematic situation" (Harel, 2008b, p. 894). The Knowing and Knowing-Knowledge premises derive from Piaget's (1971) genetic epistemology and von Glasersfeld's (1995) radical constructivism.

Informed by the Knowing and Knowing-Knowledge Linkage Premises, Harel (2013b) describes intellectual need as the perceived need to resolve "a perturbational state resulting from an individual's encounter with a situation that is incompatible with, or presents a problem that is unsolvable by, his or her current knowledge" (p. 122). This perturbation is rooted in the individual's experience within the discipline and is based on "the learner's discernment of how and why a particular piece of knowledge came to be" (Harel, 2013a, p. 8).

Intellectual need is distinct from *psychological need*, which is the motivation a student experiences to initially engage in the process of solving a problem (Harel, 2008). Harel (2013b) suggests that psychological need is often linked to students' perceived obligation to participate in school, to increase social or economic status, or to advance societal goals. In particular, a student's perception of how interesting or enjoyable they find the context could influence their motivation for engaging and persevering in solving the problem.

There is little discussion in the research literature of what might constitute evidence for students' experiences of intellectual need. In most research, claims of students experiencing intellectual need have been associated with students' expressions or activity that indicates puzzlement or curiosity. However, the data-collection protocols used in these studies did not appear to explicitly interrogate students' experiences of these psychological states or the assimilations that occasioned them.

For this study, we operationalize intellectual need by using the colloquial ideas of puzzlement and curiosity. That is, we can ask students whether they felt curious or were left wondering about something as they engaged in a task or problem context. We also distinguish these feelings vis-a-vis the intellectual content of the task from the student's interest in the underlying context—that is, an aspect of their psychological need for engaging in the task.

Research Questions

The goal of our study is to identify instances in which students experience intellectual need and some factors that are related to this experience, as well as their learning from the associated instructional videos. Thus, our research questions are:

1. How much variation of students' intellectual need is there between video sets (i.e., collections of instructional videos, pre/post-video questions, and related material for topics in first-semester calculus)?
2. Are different instructors associated with different rates of students' intellectual need?
3. Does trying an intellectual need-provoking [IN-P] task and/or watching a student problem-solving video lead to a higher rate of intellectual need?
4. Does a student's mathematical background knowledge predict their experience of intellectual need?
5. Is there a relationship between psychological need and intellectual need?
6. Is there a relationship between students' intellectual need and their learning from the associated collection of instructional videos?

Methodology

Our methodology addresses three issues: First, we needed a way to potentially provoke students' intellectual need. Second, we needed a way to adapt these provocations to an online environment. Third, we needed a way to identify students' experiences of intellectual need.

Provoking Intellectual Need: Task Construction

We needed to engage students in tasks that had the potential to provoke intellectual need. For each mathematical topic we investigated we examined the epistemology of the underlying concepts and procedures, the curriculum in which the concepts were embedded, and the research literature about the likely background knowledge of the students who would be enrolled in the class. Then, we collaboratively designed a problem for which the target concept was required to arrive at a solution and that provided an opportunity for a student to experience a perturbational state while working on the task or watching the associated student problem-solving video (described below). We also endeavored to situate the problem within a context that, we felt, might be interesting to the student population.

Adapting to an Online Environment: Student Problem-Solving Videos

We hypothesized that simply viewing and trying to solve a task might not lead a student to experience perturbation. In particular, we thought it might be possible for students to not realize that their initial way of thinking about a problem might be inadequate. Thus, we sought a way to help students identify shortcomings in their solution methods or reasoning about the tasks. To do this, we designed a "student problem-solving video" to accompany each IN-P task. In each video, a pair of actors posed as calculus students and attempted to solve the task. These videos were loosely scripted so that the actors demonstrated a variety of compelling ways of thinking about the task and concept that incorporated common student (mis)conceptions about the concept. The videos were presented to the students after they had attempted the IN-P task.

Identifying Intellectual and Psychological Need

After interrogating the concept of intellectual need, we felt that the terms "curiosity" and "wonder" were closely related descriptors. After attempting the IN-P task and watching the student problem-solving video, the students were asked the following two questions:

1. The task you just worked on dealt with the context of [context—e.g., "the speed of a baseball"]. In your honest opinion, how interesting/enjoyable was this context?
2. When you were working on this task, were there any parts where you genuinely were curious or were left wondering about something? If so, please state them in the box below; if not, please leave the box empty.

The first question was designed to enable students to self-identify an experience of psychological need; the second question was designed to enable students to self-identify an experience of intellectual need. Throughout the results, when we refer to a student experiencing an intellectual or psychological need, we mean that they responded "yes" to the corresponding question above.

Materials, Participants & Methods

Materials

We designed a set of 1-3 instructional videos for each of 30 target concepts in introductory calculus; each set of videos included a solution to one of the IN-P tasks and some additional explanation of the underlying concept. We also created a collection of multiple-choice and computational problems to be solved prior to and after watching the instructional videos, an IN-P task, and a student problem-solving video. For each video set, each student was randomly assigned to either try the IN-P task or not and to see the student problem-solving video or not.

Participants

The participants in the study were 2,733 students who were enrolled in first-semester calculus classes at one of 18 universities during the fall, 2018 and spring, 2019 semesters. The universities included both public and private institutions, ranging in size from just over 3,000 to over 35,000 students, from all regions of the United States and one institution in Indonesia. The institutions included small, private colleges through large, research-focused universities.

One member of the research team was the calculus course coordinator at their institution (a large, public university in the South-Central United States; we will refer to this as the Coordinated Institution) and incorporated a subset of the video sets into the curriculum during both the fall, 2018 and spring, 2019 semesters, for a total of 15 instructors coordinated sections. The other 18 instructors (33 instructors total) were voluntarily participating in the project research, and each selected a subset of the video sets to incorporate into their curriculum.

Statistical Design

We coded students as experiencing intellectual need if they responded "yes" to the question described in the methodology and experiencing psychological need if they indicated they found the context "somewhat" or "very" interesting. We measured students' background knowledge by the percent of pre-video questions they answered correctly, and coded students as having learned from the instructional videos if their score on the post-video questions was higher than on the pre-video questions.

Due to the nested and cross-nested nature of our data, we used Hierarchical Linear Models (Raudenbush & Bryk, 2002) to perform our statistical analysis. We use two models to answer our research questions: one with intellectual need as the outcome, and one indicating growth from pre-video questions to post-video questions as an outcome. Since both of our outcome variables were measured as a 1 or 0, the regression at the lowest level is a GLM model using logistic regression. The predictor variables in our models included whether or not the student saw the IN-P task; whether the IN-P task was computationally focused or not; the student's score on the pre-video questions, the number of the video set in the semester, whether a student watch the student problem-solving video; whether or not the student was at the large, coordinated institution; and, for the learning model, the student's response to the intellectual need question. Due to space constraints, we report results for only a subset of these variables. The models were run with about 26,000 online lessons, 1550 students, 25 instructors, 14 institutions, on 30 topics. This data set was smaller than the original dataset due to missing data, or small number of students in some classes/institutions.

Results

Unconditional Model for Intellectual Need

We ran unconditional mixed models to understand the variation at the student, instructor, and video set levels. We found that a typical student working on a typical video set from a typical instructor would experience an intellectual need in 4.5% of the video sets. However, different students have different rates at which they report experiencing an intellectual need: students 1 standard deviation less than the mean only report experiencing an intellectual need on 1.3% of the video sets and students 1 SD above the mean report it at 14.5%. There is similarly large variation between instructors (1.4% to 13.5%), and this increases to (0.4% to 35%) for two standard deviations. This means that some teachers rarely have average students (in a typical lesson) who report experiencing an intellectual need, while at the other end, some teachers have average students reporting an intellectual need on about a third of the video sets.

Because most institutions in our data set are represented by a single instructor, it is difficult to tease apart variation due to instructor and variation due to institution, curriculum, or pedagogy. To address this, we ran an unconditional model using only the data of the coordinated institution and found that the standard deviation at the instructor level was only 10% less than at the other institutions. The variation across video sets is less than between teachers or between students in a class, but the two standard-deviation range is 2% to 9.6%. This shows that some lessons are nearly 5 times more likely to generate an intellectual need than others. At the coordinated institution, the standard deviation across video sets was 20% lower.

Conditional Model for Intellectual Need

The results of the conditional mixed model with intellectual need as an outcome are displayed in Table 1. The asterisks indicate the level of statistical significance (i.e., * designates the result was significant at the p=0.05 level; ** indicates significance at the p=0.01 level; and *** at the p=0.001 level). The coefficients are given in log-odds. The percentages for the coefficients are marginal percentages given a unit increase in the variable from the model intercept, with all other variables equal to zero. The percentages are not additive like in a linear regression model, and the effect of a variable could be larger or smaller than the listed percentage depending on the values of other variables.

Variable	IN Outcome Coefficient	Marginal Percentages
Intercept	-2.12***	10.7%
IN-P Task (*IT*)	-0.294***	-2.5%
Problem-Solving Video (*V*)	-0.553***	-4.2%
*IT***V*	0.532***	6.3%
Psychological Need	0.382**	4.3%
Pre-Test Score	0.768**	9.9% per SD
Lesson Order	-0.044***	-0.4% per lesson
Coordinated Institution	-1.35***	-7.7%

Table 1. Results of the conditional mixed model for intellectual need.

We summarize these results below:

- Both the effects of trying the IN-P task and watching the video are, individually, negative. However, the effects are not additive, and there is a significant interaction term between the two predictors. Thus, students who both saw the IN-P task and the student problem-solving video were more likely to report experiencing an intellectual need than students that only saw the video.
- Typical students are about 40% more likely to report a self-reported IN if they report experiencing a psychological need.
- Students with above average pre-video achievement scores (1 SD above average), are almost twice as likely to report having an intellectual need.
- The rate at which students reported having an intellectual need decreased, on average, across the semester. Lessons near the beginning of the semester had a rate of 16.9%, while lessons near the end had an average rate of 6.9%, for students with zeros on all other variables.

Models for Learning

The unconditional Learning model shows that a typical student would improve from their pre-video to post-video score on 42.4% of the typical video sets. The conditional model for Learning shows that there is a significant positive association between experiencing intellectual need and learning. Typical students show evidence of learning on about 7% more lessons if they experience an intellectual need, an increase of about 23% (from the average/intercept of 29.9% up to 36.8% of lessons) over students that do not experience an intellectual need.

Discussion

Methodological Contributions

One significant contribution of this study is the methods and methodology to empirically identify students' experiences of intellectual need. This included developing tasks to provoke intellectual need, videos related to each task to help students recognize the need, and survey questions—administered at the point where we thought students might be experiencing disequilibrium—to enable students to report feelings of psychological and intellectual need.

There are several potential shortcomings of the methodology. We don't know whether "curiosity" and "wonderment" are the most appropriate terms to identify intellectual need, and students' self-identification might be inaccurate. Students might have been reluctant to respond affirmatively to the intellectual need question because doing so would require them to write additional information, this is supported by the significance of the Lesson Order predictor. Finally, we don't know the extent to which intellectual need can be provoked by a single task, even when the task is accompanied with a student problem-solving video. Instructor interaction and intervention might be essential to moving students into a state of disequilibrium, and our methods might have been insufficient to actually provoke genuine intellectual need.

Factors that Affect Intellectual Need

Overall, there was a relatively low rate of students reporting an experience of intellectual need. However, instructors—and, implicitly, the ways they incorporate the video sets into their instruction—are associated with different rates of intellectual need. Taken together, the results suggest that the instructor variation in our model is due mainly to differences in instructors, rather than other institutional factors. Thus, there is a complex interaction between pedagogy, curriculum, and students' interaction with the out-of-class learning materials, and this interaction needs to be studied in more detail.

Students were much more likely to experience intellectual need in response to some video sets than others. This means that some mathematical topics, tasks, or problem-solving videos were more effective at helping students experience and identify a state of disequilibrium. The relationship between video set content and intellectual need warrants further investigation.

There was a significant relationship between students' experiencing intellectual and psychological need. One explanation for this result is that there is a significant cognitive or emotional overlap between the two types of need, and that it is important to consider problem context when constructing an IN-P task. Alternatively, it could be that there is an overlap between our operationalizations of the two concepts, making it difficult for students to accurately distinguish between them.

Students who had more extensive background knowledge for a task were more likely to experience an intellectual need than other students. One explanation for this result is that students need a certain level of knowledge about the background mathematical concepts to engage in the IN-P task in the intended way. Alternatively, students might need the background knowledge to *identify* their experience as one of intellectual need. Both explanations suggest that IN-P tasks need to be carefully tailored to particular student knowledge and characteristics in order to provoke intellectual need.

Beyond the students' own background knowledge and other characteristics, it appears that the ways in which we structure the video-watching process can impact the students' experience of intellectual need. Students who (only) tried the IN-P task or (only) watched the student problem-solving video were less likely to experience intellectual need. However, for students who watched the problem-solving video, those who also tried IN-P task were more likely to experience intellectual need. This result suggests that merely provoking intellectual need is not a straightforward process, and that it would be useful for educators to have a framework to support the design and implementation of IN-P tasks.

Relationship between Intellectual Need and Learning

There is an association between a student experiencing intellectual need and demonstrating learning from the instructional videos. This result aligns well with the theory of intellectual need, which posits this relationship between need and learning. However, our measures of learning were relatively unsophisticated, and it is possible that we didn't accurately assess the depth or sophistication of students' learning. Furthermore, learning is often intended to take place over an extended period of time, rather than across a handful of short instructional videos, so we might not have adequately measured the intended constructs.

Conclusion

This study makes a significant methodological contribution to the design and evaluation of learning environments and materials. Our methodology and methods provide a first step into empirically identifying students' experiences of intellectual need and connecting those experiences to their learning. Our results also shed light on some of the factors that might impact students' experiences of intellectual need and how these factors influence learning. The relationship between intellectual need, learning, structuring the students' experience of the video sets, the students' background knowledge, and the instructor's pedagogy is complex. Taken together, these results highlight the importance of continuing to study intellectual need and to create a framework for helping instructors design and implement intellectual need-provoking tasks.

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