Implementation of a Problem-Based Approach in an Undergraduate Cognitive Neuroscience Course

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In this article we describe a modified implementation of an instructional strategy known as *problem-based learning* (PBL) in an introductory cognitive neuroscience course (Brain and Cognition). Our goal is to describe the principles of PBL that we found effective and to demonstrate how these principles fostered our continued restructuring of this undergraduate course. We share the details of our evolution over a three-year period because we found that the implementation of PBL is not an easy transition. However, it was a positive experience for us and our students, and the course is now very well received. Although we implemented these principles for a cognitive neuroscience course, any course in which the content can be introduced through large problems could take advantage of this approach.

Before the first year of our course restructuring, the instructional method for Brain and Cognition was largely lecture and demonstration. We were concerned that students did not participate actively in class discussions and that they appeared to transcribe the lecture without much synthesis or analysis. The rote memorization strategy adopted by our students typically does not support long-term retention (Ausubel 1963; Siegl and Shaughnessy 1994). In addition, this transcription/memorization approach does not work well in a domain like cognitive neuroscience in which there are few hard facts about how the brain works to support higher mental functions like memory, language, or intelligence. We wanted the undergraduates to become more engaged in the learning experience and to use the tools of neuroscience to solve problems in their own domains. To increase student interaction, decrease lecture time, and provide students with meaningful learning activities, we changed the instructional format to include authentic problems in a PBL format. We use our case to describe principles of PBL that we found most critical to consider when meeting the instructional goals for the course.

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Goals and Principles of PBL

Problem-based learning is an instructional strategy that places students in problem-solving situations (Albanese and Mitchell 1993; Barrows and Myers 1993; Hmelo 1998; Savery and Duffy 1996). Though it was originally implemented as an alternative curriculum in medical schools, the use of PBL has been extended to an increasing number of areas including business, education, architecture, law, engineering, social work, and high school (Savery and Duffy 1996). Instructors who practice this method use fewer lectures and emphasize independent learning and problem solving. Goals of this strategy include the development of an integrated knowledge base that is better retained for later use in real-world situations and the development of skills for effective collaboration with peers (Barrows and Myers 1993).

Unlike other methods, with PBL a problem is presented before the introduction of concepts that are needed to solve it. The problem provides the context from which the concepts and issues emerge. During this process, students develop their own questions and frame the concepts in their own words rather than passively absorbing them from the instructor's lecture (Albanese and Mitchell 1993; Savery and Duffy 1996).

PBL, along with other constructivist instructional strategies, adopts several instructional principles. These principles address the role of the problem, the learning environment, the learners, the teacher, and the learning process (Honebein,

Duffy, and Fishman 1993; Savery and Duffy 1996). In our implementation, we focused on three aspects of PBL: the problem, learners as collaborators, and learners as directors of their own learning.

The Problem: Contexts for Concepts

Learning activities should be anchored in a larger context that includes an authentic task. Problems used in PBL are often ill structured in that they are vaguely defined, have unstated constraints, and may include multiple viable solutions and solution paths (Barrows and Myers 1993; Jonassen 1997). Well-structured problems have a known goal (answer) that the student provides. With these traditional problems, all of the elements of the problem are presented, and there exist convergent, correct answers with a preferred solution process through which this answer is obtained. In addition, the use of authentic problems "should help learners develop ways of thinking and acting that characterize the culture or professional community" (Lebow and Wager 1994, 233).

Given that the problems are authentic, the learning environment should reflect the environment in which that type of problem would normally occur. However, the complexity may be reduced so that it is appropriate for the students (Savery and Duffy 1996). For example, in our class, students did not deal with real patients but rather with simulated situations and case studies.

Students as Collaborators: Considering Alternative Perspectives

The learning environment should also prompt students to consider alternative hypotheses (Honebein, Duffy, and Fishman 1993; Savery and Duffy 1996). Working in groups provides the opportunity to generate and investigate multiple perspectives and also to share the workload (Duffy and Cunningham 1996).

Student-Directed Learning: Learner Ownership

In PBL, students must take responsibility and seek resources to solve the problem as the instructor provides support that encourages progress. The learner develops ownership of the process that leads to the solution. Therefore, problems should be developed in such a way that students will adopt them as their own (Savery and Duffy 1996).

The Effects of PBL

Research on PBL shows promising results. In studies on the use of problems in college (Arambula-Greenfield 1996; Duch 1996; Mierson 1998) and college-prep courses (Roth 1992), student satisfaction was high. Although not all students respond favorably, students with PBL instruction (e.g., Percac and Armstrong 1998;Verhoeven et al. 1998) did as well as students in non-PBL courses. Further, Hmelo (1998; Hmelo, Gotterer, and Bransford 1997) found that learning strategies and reasoning processes were more professional in PBL than in non-PBL medical school students.

Given positive results with previous studies of PBL and our own assessment that our cognitive neuroscience course would lend itself well to the use of problems, we began a restructuring effort. We gleaned aspects of the PBL approach that we considered most critical: that authentic problems be used to provide a context for learning concepts, that learning be student directed, and that student collaboration be fostered to generate and share different perspectives.

Modifications of PBL for Cognitive Neuroscience

The Course

The central goal of Brain and Cognition is to provide students with an understanding of how researchers draw conclusions about the human brain on the basis of behavioral and neuroscience data. In addition to providing an introduction to neurons and brain areas, we cover a range of human abilities including perception, memory, attention, consciousness, and language.

This three-credit course typically has an enrollment of twelve to twenty-four undergraduates from a variety of majors. During our implementation, data were gathered through observation, instructor and student interviews, student questionnaires, and document analysis. Schuh conducted the interviews and gathered the observation data, and Busey taught the course. During the 1997 class, observation took place during regular class meetings over a five-week period. During the 1998 class, observation extended across the entire semester. Schuh interviewed three student volunteers at the end of each semester and interviewed the instructor twice each semester. Students also completed questionnaires both semesters, although the questions were adjusted each year to reflect changes in the course. Each year, students completed the university course evaluation as well. During the 1999 class, the instructor continued the implementation and relied on university course evaluations to gather information.

Development of Initial Version of Problems

We initially focused on problem development. We attempted to develop problems that captured the relevant concepts and principles of the domain and were similar to the types of problems that cognitive neuroscientists in various venues of the field might address (Duffy and Cunningham 1996; Savery and Duffy 1996). Our goal was for students to understand the concepts and to learn the processes of science.

During the first year, the problems placed students in a number of roles. For the first problem, they were on a development team for a virtual neuron. The purpose of this problem was to provide a context for understanding basic neuron functions. The second problem described a patient with epilepsy (Jane Doe) who was considering brain surgery to remove part of her temporal lobe. The students predicted what cognitive functions might be lost as a result of the surgery and communicated their findings to the fictitious patient in a research symposium. Students worked in groups to complete these two problems. The final problem was more reflective in nature. The students were to write a letter to their Congressman requesting funding for cognitive neuroscience research. We hoped that the reflection process, another characteristic of constructivist learning and PBL (Savery and Duffy 1996), would be an opportunity for students to synthesize what they had learned and communicate it to a layperson.

The problems were all ill structured because each had a number of solutions and solution paths. In addition, one or

more elements were unknown at the outset (e.g., we did not list the tools that could be used to gather the necessary data, and we provided little or no information about the content areas or background literature needed to solve the problem). Finally, all problems had unstated constraints in that we provided no limitations on choosing neuroscience equipment or experimental tasks. We embedded the problems in writing assignments so students could communicate their synthesized understanding of the material and a justified problem solution.

After the first year, we felt that the course modification was successful given student feedback and the quality of the papers submitted. However, as expected, the course and the problems needed adjustments to better align them with the principles of PBL. Using a formative process, we continued to refine the course to become fully problem-based.

Adjusting the Problems: Improving the Context

Perhaps the most critical outcome of the first year was our growing concern about the problems providing a context for the course content, a foundational characteristic of PBL. During that year, we used lectures more often than we had hoped. In addition, we had difficulty creating problems that prompted students to ask questions and seek information to address the issues. We believed that if we improved the problems so that they would be better catalysts for the content, then the instructor could minimize his role as the information provider and learning would become more student directed (Arambula-Greenfield 1996; Barrows and Myers 1993; Duffy and Cunningham 1996; Savery and Duffy 1996). The next step in our process was to find a way to have the course more closely organized around four problems.

To begin our next phase of problem development, we used the patient with epilepsy problem as a model. It had fostered the best student papers and had best integrated the concepts the previous year. During the symposium that followed this paper, we found that many of our students had become passionate about the research and topic areas they had researched, showing ownership of their own learning processes. In addition, students articulated key concepts (e.g., effects of the lesion on cognitive functions) related to our course objectives. We discarded the other two problems from the first year and developed new ones. We began with the learning outcomes and content that we hoped would emerge. We also had to anticipate and understand the types of questions that we wanted the students to encounter while solving the problem. It would have been ideal to develop this type of problem in our initial effort, but it was only after our first implementation that we were able to identify how the problem raised these issues.

First, we assigned an individual problem for which students were to speculate about the brain's influence on a particular behavior of interest to them. The next problem placed the students in the role of consultant to a group of engineers developing a face-recognition component for an ATM. For this problem, students examined the human visual system and extracted those essential functions that might be useful for the machine implementation. The problem could not be addressed without understanding many of the concepts related to the human visual system.

For the third problem, students proposed an assessment to determine the extent of an amnesiac patient's disability and to clarify the role of particular brain areas in human memory. Because we had not discussed memory before students attempted the problem, they were prompted to learn the roles and relationships of different types of memory. This problem provided a context in which brain functioning that relates to memory could be explored. During the previous year, this content had largely been addressed through lecture.

We ended the course with the successful problem about the patient with epilepsy from the previous year. We used the same specifications and kept the research symposium as the capstone activity for the problem. We added a videotape of a child who had undergone radical surgery (removal of her left hemisphere) as treatment for a severe case of epilepsy. The video provided an authentic component to the problem—a patient's concerns about reduced postlesion cognitive functioning.

In addition to more careful specification of the problems, during the second year we also provided more time in class for the students to work together. The lectures that did occur introduced new problems (set the context) or provided clarification and demonstration of an aspect of the problem with which the student groups had struggled. Thus, the problems were not an addition to the class: they provided the content.

Another concern we had after the first year centered around the types of questions students asked as they worked on the problems. These questions were an indication that the learning was not student directed.

Allowing for Student-Directed Learning

During the first year, we found that the specifications for the papers that students submitted following a problem were too broadly defined in terms of the evaluation criteria. We had hoped that questions about the content and problem-solving process would arise as students sought resources and information to solve the problems. However, students focused on what the instructor wanted and how the solutions would be assessed. We wanted ill-structured problems, as PBL prescribes, but we did not want students' efforts to be directed toward the product rather than the content and the process. On the basis of student feedback, we continued to develop a process to ensure that the problem specifications and assessment criteria were more carefully described without restricting the possibility of multiple solutions. Table 1 contains the rubric used for the epileptic patient problem. The problems continued to be ill structured. However, the assignment criteria were well defined in that the classroom and assessment questions were anticipated and specified up front (e.g., what constituted a successful solution to the problem, how the solution would be evaluated, and what resources were available to the students).

We adapted this assessment method from other colleagues and found that it works well with the problems in this course. The rubric, which the students received along with the problem specification, covertly reinforced the process of science and provided a structure that guided them in a way that allowed many

Table 1.—Grading Criteria: Counseling an Epileptic Patient

Section	Possible points	Your points
Introduction		
State goals clearly and concisely, then follow them.	± 1	
Choice of task		
Provide previous evidence that your task might be performed in part by neurons in the left temporal cortex.	± 1	
Choice of experiment and equipment		
Demonstrate that the experimental design isolates the particular task.		
Demonstrate that the cognitive neuroscience equipment is appropriate for answering questions and advising the patient.	± 1	
Data analysis		
Clearly state how the results will be used to advise the patient.	± 1	
Reliability		
Identify potential design flaws or difficulties with current cognitive neuroscience techniques.	± 1	
Presentation		
Clearly communicate design and analysis in the research symposium.	± 2	
Team contribution		
Evaluate whether your teammates feel that you contributed appropriately.	± 1	
Final grade: 40 ± _____ = _____		

Note: Within this rubric is an explicit expectation that students will perform at a passing level (for this course we designated that as a "B"). The total point value for each project was 40 points, although this is obviously an arbitrary decision. If a student or group of students produces a document that shows proficiency, they neither receive nor lose points for that area. Points were added or subtracted on the basis of deviation from that proficiency level.

possible solutions to the problem. It specified a structure for the assessment of the paper, a structure for reporting a research plan, and a method for solving problems within the neuroscience community. For example, the criteria prompted students to include justification for the tasks included in their designs. They provided previous evidence (thus a need to seek other sources) that their proposed task addressed the problem and developed and described a design that supported this task. Although students did not collect the data, they reflected on the proposed experiment. They justified the data collection equipment used and discussed the implications of the equipment use for the patient (many procedures are invasive). They also considered how to advise the patient and expressed the limitations and flaws of the study. We did not discuss the process outlined in the criteria with students in the class.

Although this well-defined specification may seem to be a misnomer in terms of problem-based learning, it is in fact one way to provide students with an outline of the process that cognitive neuroscientists embark on when approaching problems. This allows them to experience the process while setting aside the performance goals of the assignment.

Managing Group Interactions

The improved problems provided opportunities for student-directed learning. In addition, we wanted to foster group interactions to generate multiple perspectives, as is recommended for PBL. Assignments of group work often provide a number of learning and organizational issues that typically are not addressed in traditional classrooms. Concerns include how to assign students to groups, how to manage in-class group work time, and how to address social-loafing (Meyers 1997). Our decision to assign students to groups was influenced by the multidisciplinary make-up of the class. At the beginning of the semester, we gathered personal information from students, including their majors, minors, and areas of interest. We typically assigned individuals to groups of three or four, a recommended size for productive group work in problem solving (Woolfolk 1998). In this way, we were able to "load" the groups with individuals with a variety of skill strengths. For example, we believed that computer science majors would be particularly helpful for the machine vision problem and distributed these individuals throughout the groups.

In his review of student participation in small-group activities in psychology classes, Meyers (1997) offered the following suggestions for enhancing the effectiveness of small groups: ensure that the task structure is amenable to group work, use formal student evaluations, and support the group structure. We believe our problems were amenable to group work in that students were able to divide up tasks without our assistance. Our evaluation strategy included instructor, peer, and individual evaluations. Although there were occasional problems within individual groups (e.g., scheduling), overall the students responded favorably to the group process. One student stated that he learned more in completing the group problems because "you were able to do research on specific areas and then you learned what the other people in the group found out also" (Student D, January 19, 1999). Although minor problems existed, the group process and group diversity provided an excellent opportunity for students to share multiple perspectives.

We feel that our concentrated focus on the characteristics of PBL (the problem, student-directed learning, and collaboration) resulted in a course that engaged students in the learning process. However, it is also important to consider the response of the students to the new instructional strategy.

Evaluation of the Course

Assessment

Traditional evaluations often use assessment techniques and statistical analyses that are inappropriate for the evaluation of problems in our course. We consider assessment and evaluation to be a critical step in course development, so

we relied on a more qualitative approach. One goal of our restructuring was to move away from rote memorization and to focus more on the understanding of the concepts and the processes of science. The quantitative measures that we had used in the course before the restructuring (quizzes, exams) no longer aligned with the instructional format. Rather than memorization of facts, we sought indicators of the students' development as problem solvers by considering the quality and insight of their papers and their enthusiasm as learners.

Our qualitative assessment of the papers indicated that the concepts were more likely to be understood within the context of the problems. During the second year, the students understood the concepts better and at a deeper level. Further, the content that had previously been isolated bits of information was now integrated into the problems. Students described cognitive functions, not from a textbook point-of-view but to provide information to Jane Doe (in the epileptic patient problem). We found greater personal synthesis, evaluation, and reflection because the problem criteria were better specified, which allowed the students to apply their efforts to solving the problems rather than being caught up in the performance goals of the assignment (i.e., what was needed to get a good grade).

Addressing the PBL Principles

Given the framework for our implementation of PBL, we considered the problems, student-directed learning, and collaboration among students from the students' perspective. Some students indicated that the problems did prompt the learning of the concepts. For example, one student shared, "It [would be] really easy [for the instructor] to sit down and say, 'OK, this is how the visual system works,' but by requiring us to write a paper about how a computer could recognize faces, I was forced to think about how the visual system worked and try and represent it in a logical way that would be, you know, a good argument for how a computer could go about using that. I think it's really easy to package the information, but you never learn how to use it" (Student F, January 21, 1999).

This student also explained how the learning that occurred in the papers provided a foundation of concepts stating, "I learned the most from that paper [on machine vision] out of all the other assignments because I kept coming back to that for every other assignment because that gave me a basic understanding of all the other structures that we studied." He also stated that this project was the most frustrating. Thus, the project better displayed the course content than the problem from the previous year. Another student, who also identified the machine vision problem as his favorite, stated, "I believed because I enjoyed it more so I was more apt to look into it in depth" (Student D, January 19, 1999).

We also found that the students' motivation was based on the problems and a self-imposed sense of responsibility for their own learning. One student referred to this ownership as our "throwing the ball into their court." As Student F stated, "[I]t was my responsibility, that it was my job and I really liked that" (Student F, January 21, 1999). Another student mentioned that the papers motivated him in class. This type of internal motivation is not unusual in PBL. Barrows and Myers (1993) stated that student motivation in PBL is not superficial (based on grades) but is intrinsic. The motivation is to understand the problem and study on the basis of the perceived relevance of the problem. The students that were interviewed did not express any concern about being presented with problems that were not solvable in the conventional sense. In fact, all three of these second-year students felt that it was a positive aspect and stated that having unsolvable problems was fun. Student F explained, "It's always fun to work on things like that because nobody knows, so you can say just about anything as long as you can give a logical reason for it and a way to test it."

Students commented on the time commitment of the projects and also their freedom to make decisions about the projects. "It was more labor intensive because of that [not being presented information], we looked up things, but looked at what we were interested in. If he would have assigned an area, we wouldn't have been free to decide what we wanted to do. Since it wasn't specific we could do what we wanted. If he had talked about it we would just rely on our notes. This way we could be creative" (Student C, December 8, 1997).

Throughout the two years when students were interviewed, there were various reactions to solving problems in the groups. During each semester, students worked on half of the problems individually. There were problems with "social loafing" when students would not complete their tasks. Students acknowledged positive aspects of the process as well. They commented that the problems went quicker, that they could bounce ideas off of one another, and that they could capitalize on one another's strengths. Thus, although there were problems with the group collaboration, there were also gains in terms of sharing perspectives and the workload.

Traditional Course Evaluations

Each year we used different means of assessment, but the constant across the years (including years prior to the restructuring) was the university course evaluation. We identified four questions that were answered each year and seemed least likely to reflect only the improved teaching skills of the instructor. The questions and the mean values for a five-year period are included in table 2. During the first two years, the course was taught traditionally—largely lecture and demonstration. The implementation began in 1997. A one-way analysis of variance revealed that the improvement seen in the data was statistically significant, $F(4, 15) = 4.64$, $p < .05$. In addition, the values for 1999 were greater than the ratings for 90 percent of the courses taught at Indiana University. Thus, the course was very well received by the students.

A midsemester questionnaire in 1998 supported the improved course evaluation results as well. Student responses ($N = 7$; 50 percent response rate) were positive, stating that they had learned in this course as much as (43 percent) or more than (57 percent) they did in other higher level courses. They also enjoyed the course as much as (43 percent) or more than (57 percent) the higher level courses.

Lessons Learned

Implementing a new instructional strategy is not simple or easy. In restructuring

an undergraduate cognitive neuroscience course, we chose aspects of PBL that we could implement on a small scale initially, gathering data that would guide the development of the course as it progressed. This process provided an opportunity for the course to gradually evolve into a format that allowed greater student responsibility for learning, use of problems similar to those that a specialist in the field would have, and use of group work during class to determine what topics needed to be explicitly addressed in lecture and discussion.

Our weekly conversations revolved around the day-to-day functioning of the class: Was there too much lecturing? Did the students understand the material? Were the concepts emerging? Were the students on a path to a problem solution that was viable?

Through our own questions we learned a number of lessons. We made the critical realization that the problems, although ill structured and aligned with the subject area, did not in and of themselves necessitate that the concepts be understood. Working from our learning objectives and course goals to develop authentic problems was more successful than beginning with an authentic problem and trying to structure it to meet the objectives and goals.

Second, the idea that an ill-structured problem could require well-structured product specifications was critical. We found that if we provided a framework for reporting the problem solution (while not limiting the process or the potential solutions), students asked us different types of questions. It seems that students will ask a certain number of questions. If they are not about the assignment, then they are about the content.

Finally, student ownership, either individually or as a group, will emerge if the problems are interesting and enjoyable and if students have no other alternative but to fend for themselves. Although we provided support for the students, getting out of their way so they could stumble across questions that interested them was

Table 2.—Summary of Course Evaluation Results for Four Questions over a Five-Year Period

Year	N[a]	Quality of course[b]	Subject learning[c]	Quantity of learning[d]	Problems solving[e]
1995	5	2.80	2.20	3.20	2.50
1996	11	3.27	3.00	3.00	2.27
1997	7	3.43	3.29	3.71	3.14
1998	13	3.15	3.31	3.31	3.08
1999	17	3.53	3.41	3.47	3.24

Note: Responses ranged from 0 to 4 (with 4 being *strongly agreeing with a positive statement*).
[a]Number of students completing course evaluation; total students in the course varied.
[b]"Overall, I would rate the quality of the course as outstanding."
[c]"Course assignments help in learning the subject matter."
[d]"I learned a lot in this course."
[e]"I developed the ability to solve actual problems in the field."

Table 3.—Suggested Problems for Abstraction in a Variety of Domains

Domain	Possible abstracted problem
Chemistry	Students propose a novel application based on electrical or chemical properties for a company that produces carbon-based nanotubes.
Political science	A political candidate for a national office is interested in the impact of vote-by-mail on voter participation in western states. The students are asked to study this issue as part of the candidate's campaign plan and also the impact that it may have on the outcome of the election.
Computer science	Students modify an existing web-based search engine to match the specific structure of an existing database such as the U.S. Patent database or the Associated Press photo archive.
Economics	Students prepare a presentation for a town meeting that addresses the viability of moving from a property-based taxation system to an income-tax based system to pay for local schools.
Mathematics/probability	As casino owners, students determine the house odds on a new game of change and set up guidelines for pay-offs accordingly.
Psychology	Students consider all alleged daycare child sex abuse case and propose and evaluate methods for determining whether the children are accurately describing the events that may have occurred.
Anthropology	Students write and produce a documentary on the social behaviors of the Neanderthals on the basis of artifacts from a recent Neanderthal archeological dig.
Business	Students evaluate the possibility of taking an existing company public.
Law	Following the lead of the Chicago cases, students are asked to present a defense for particular death penalty cases in which alleged racial bias exists.
Cognitive science	Students develop a simple system of rules to explain the behavior of a complex system (e.g., birds flying, fish schooling, ideas spreading through a culture) that will be well understood at an interdisciplinary symposium.

Note: These are suggestions that we have developed as users of PBL, not as experts in the specific domain, and thus they should be viewed as starting points by instructors in different domains.

necessary to encourage the learning process in PBL.

Recommendations

Cognitive neuroscience is a course for which many faculty have a limited understanding of the concepts and problems. Given that, it may be difficult to generalize our description to other disciplines. However, we believe that the underlying issue does not deal with the content, but with the acknowledgment that we are problem solvers within our fields. First, we need to acknowledge that there are ill-structured problems in our fields, thus making PBL a valid instructional strategy for our own use. Table 3 contains a summary of potential problems in a number of domains.

Our recommendation for those who are ready to restructure their course into a problem-based format is to choose those principles that best align with your focus and begin to address them, developing the course in a formative manner, gathering a variety of data, reflecting, and continuing to implement changes that move you closer to the long-term goal. Incremental small-scale changes benefit students and allow the instructor to gradually move a course towards problem-based learning.

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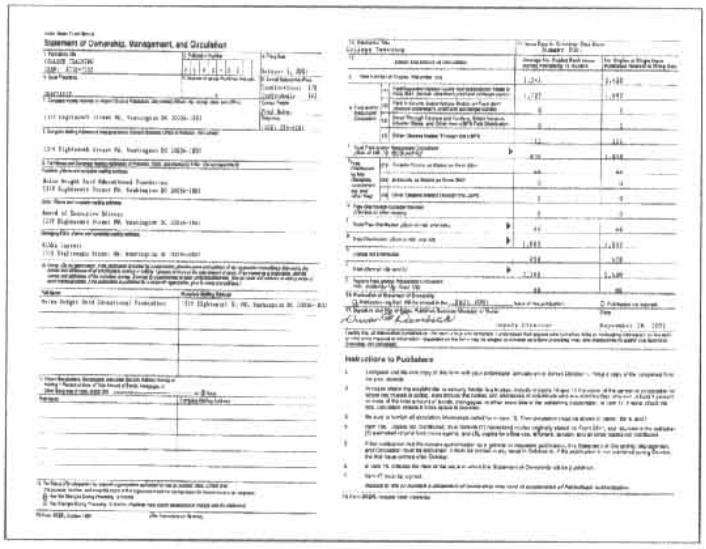
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