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ABSTRACT

Methods of optimizing instruction through the use of course knowledge portrayal methods were studied, based on a series of experiments conducted over 6 years. Sixteen university courses in the sciences, social sciences, and humanities were investigated through the application of cognitive theory to instruction. Attention was first focused on portraying the knowledge structures in the courses. Next, these knowledge structures were used as the basis of research into student learning in the course (i.e., to measure gains in student knowledge and to test the degree to which they predicted course achievement). Current analysis of the knowledge structures using feature analysis and network analysis demonstrated the kinds of analytic processes required to understand the main concepts in the course and the degree of concurrence of relationships within and between concepts. The research is based on cognitive theory applied to instruction. The concept was the unit of analysis; the methods were different forms of conceptual analysis. The application of conceptual portrayal to instruction and to learning is illustrated with reference to a university course. In addition, a taxonomy illustrating relationships between concepts is presented. (Author/SW)

Instructional Development Through Knowledge Portrayal

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Paper presented at the annual meeting of the American Educational Research Association, New Orleans, 1984. This research was supported by a grant from the Fonds Formation des Chercheurs et Actions Concertee, Quebec.

This study focusses on methods of optimizing instruction through the use of course knowledge portrayal methods. In postsecondary education, student achievement depends upon knowing the structure of the subject area and upon being able to apply the relevant analytic processes. The data on which this study was based come from a series of experiments conducted over a period of six years on sixteen university courses in the sciences, social sciences, and humanities. During the first three years, the research concentrated on portraying the knowledge structures in the courses. In the second three years, these knowledge structures were used as the basis of research into student learning in the course. The knowledge structures were used to measure gains in student knowledge and to test the degree to which they predicted course achievement. Current analysis of the knowledge structures using feature analysis and network analysis demonstrates the kinds of analytic processes required to understand the main concepts in the course and the degree of concurrence of relationships within and between concepts.

The research is based on cognitive theory applied to instruction. The unit of analysis is the concept and the methods explored here are different forms of conceptual analysis. The results of these analyses are viewed in conjunction with the relationships found between concepts in course material. The application of conceptual portrayal to instruction and to learning is illustrated with reference to a university course.

Concepts and relationships

The minimal, although not necessarily optimal, unit of analysis for a knowledge structure is the concept and its relationships. By concept, we mean a word or phrase which serves as a unit of thought or meaning. A concept is not considered to have finite boundaries but rather a center of density, although features can be distinguished. Relationships between concepts are the most readily observed and codified units of organization.

In our research into the knowledge structures of university courses, we focussed on the closest relationships between key concepts in each course (Donald, 1983). It should be noted that we worked with the professor's knowledge structure rather than a general content structure or a curriculum structure. In each of 16 courses across disciplines, the professor was asked to describe the relationship between the concepts he or she had judged closest in the development of a tree structure of the key concepts. From these relationships a taxonomy which described categories of relationships between concepts was created.

Kinds of relationships between key concepts.

We could discriminate two main kinds of relationships: those based on congruency or similiarity, and those based on contingency or dependency (Table 1). In a sample of 252 relationships examined between key concepts linked in the tree structures of 16 courses, 60 percent were based on similarity and 40 percent were dependency relationships. The most frequently found relationship (42%) was structural or hierarchial in nature, that is, concepts had a set-subset or part or kind relationship between them. The remaining similarity relationships (18%) were more primitive: concepts were associated as parts or kinds of a superordinate term, had a feature in common, or had a functional similarity, that is, a similar outcome or purpose. These findings suggest that proximal methods of portrayal, as advocated by Carroll & Chang (1970); Kruskal (1964); Nagy (1978); Yackulic (1981), although they do not explain a relationship, do not do injustice to 60 percent of conceptual relationships, since similarity relationships could be assumed to be proximal by definition.

The remaining 40 percent of the relationships between the concepts were contingency or dependency relationships, in which a change in one concept implied a corresponding change in the other. Procedural relationships (10%) described steps, order or sequence; logical relationships (18%) showed a conditional order; and causal relationships (12%) showed an explicit cause and effect linkage. The distribution of dependency relationships differed across courses more than that of similarity relationships. All 16 courses had similarity relationships and, within that category, structural relationships. Most of the procedural relationships (83%) were found, however, in the five science courses as were a majority (54%) of the causal relationships, whereas relationships in science courses represented 43% of the total relationships studied. The social science courses had 62% of the logical relationships although they represented 37% of the total relationships. All courses employed at least two kinds of relationships between the key concepts. Three courses, in the psychology of thinking, moral philosophy and classics, used only similarity relationships between the key concepts. Thus, in some courses, where similarity relationships dominate, proximal methods could make a contribution to the understanding of relationships, albeit at the surface level of analysis. In other courses, and particularly science courses, they would result in an inaccurate portrayal because many of the relationships between concepts are not based on proximity or similarity but on contingency or dependency.

Conceptual portrayal and instruction

Methods of conceptual portrayal for instructional purposes are essentially methods of interpretation and must take into account the kinds of learning intended to occur. One categorization (Reigeluth et al, 1983) divides the kinds of learning into four types: facts; concepts; principles, propositions or rules (used here synonymously); and procedures or strategies for problem solving. Facts are considered to be empirical and require minimal interpretation although they may require a series of examples. Concepts, depending upon how simple or complex they are and how concrete or abstract, will require a varying amount of interpretation by such methods as attribute analysis (Tiemann & Markle, 1976), feature analysis (Bever & Rosenbaum, 1971; Soltis, 1978) or network analysis (Preece, 1976, Rumelhart, Lindsay, & Norman, 1972, Shavelson, 1974). Principals or propositions consist of relationships between at least two concepts and introduce an additional level of interpretation which involves methods such as semantic analysis, discourse analysis and text analysis (Frederiksen, 1975; Miller, 1971). Problem-solving requires the use of all the analytic strategies used to interpret concepts and propositions applied to novel situations (Egan & Greeno, 1974; Greeno, 1976, Newell & Simon, 1971). With reference to an instructional development model, then, conceptual portrayal provides a basic building block at a level micro-analytic to propositional analysis and problem-solving.

Methods of conceptual portrayal have, however, been found to be highly useful for instructional development purposes. Our work in course content analysis enabled us to explain why students experienced difficulty in certain courses, for example. In an applied social science course where students expressed confusion, examination of the tree structure showing highly complicated relationships between the key concepts was a clue to the difficulty. In the course students were expected to problem solve using complex relationships between concepts when they were not familiar with the concepts themselves. In a chemistry course, the key concepts were both more numerous and more abstract than in other courses, but also related to each other in ways unexpected for chemistry courses, so that students were required to make a major shift in learning strategy in order to be successful in the course. A comparison of kinds of key concepts or of tree structures across courses suggested different teaching strategies. Matrix analyses of the degree of relatedness among key concepts led to a reorientation in course structure. Although these methods have proved useful in diagnosing instructional problems, they suggest hypotheses rather than provide proof of a learning mechanism.

The relationship of knowledge structures to learning

How do we explain the relationship between knowledge structures and student learning? A recent attempt to explain this relationship, elaboration theory, suggests that retrieval from memory depends upon the elaborateness of the network encoded at comprehension (Anderson, 1976; Carson & Reigeluth, 1983; Jacoby & Craik, 1979; McCown & Miller, 1983; Tobias, 1983). The mechanism underlying ease of retrieval has been described as repeated subordinate referential coherence (McCown & Miller, 1983). Our studies suggest that the references are not necessarily subordinate, nor must they be repeated, but that the essential feature is the coherence of the concept elaboration, where coherence is defined as the relationship of components in an integrated structure. This is closer to the idea of knowing the structural relations between elements in a domain (Bruner, 1960; Greeno, 1976; Riley, 1984) which differentiates between meaningful and rote learning and between successful problem solving and cook-book application. Once all the parts or conditions are known, the concept or proposition becomes a schema as Bartlett (1932) and Rumelhart & Ortony (1977) have described, a data structure containing the network of interrelationships that is believed to generally hold among its constituents.

The elaboration of a concept should enable it to be reliably useful, without errors or ambiguities, so that it can be applied easily and flexibly. Reif (1983) has pointed out that conceptual building blocks or concept schemas of this nature are essential in the quantitative sciences. He has postulated a set of procedures for interpreting scientific concepts which would appear to have more general applicability. What is most relevant to our goal of representing knowledge structures is his attempt to interpret concepts by means of procedural specifications and the specification of concept values and independent variables. A procedural specification goes beyond a definition or informal description of a concept by providing a step-by-step procedure specifying how to identify or exhibit the concept, thus being a precision of an operational definition. The specification of concept values clarifies the elements needed to specify the type of value and the unit or units of measurement. The specification of independent variables which affect the concept sets the conditions or framework for application of a concept and thus entrenches it in memory. Reif's specification procedures suggest more precise approaches to producing a coherent concept or a schema. We have developed and tested different methods to provide this specification. Some focus on units or features and some on relationships.

Application of conceptual analysis to a course

To demonstrate the products of these various methods of specification or analysis, I am going to use, as an example, a course which exhibits both structural and dependent relationships, frequently in parallel, and which employs concepts which are relatively novel to adults. It is an introductory law course on Tort, from the latin for "wrong", in which knowledge of the key concepts correlated significantly (.45, $p < .01$) with student achievement in the course, and in which students made a large gain in knowledge of the key concepts (38%) compared to the gain in other courses over a two-semester period. A content analysis of concepts used in the course showed that there were 68 concepts specifically relevant to the course of which 14 were key, that is, main or linking concepts. The key concepts were analyzed for their relative importance, familiarity, abstractness and close relationships between them, the latter by means of a tree structure as seen in Figure 1.

Tree structure analysis

Tree structure analysis has been used to establish the network of relationships among concepts in a unit of instructional material. The method for creating a tree structure was to instruct the professor to link the two most closely relate key concepts, from the course, then to link the concept most closely related to one of them, and to continue until all key concepts were linked (Shavelson, 1974). The resulting tree structure showed the dominant relationships in the course. One drawback of the method was that it imposed sequentially greater limitations on the linkages, which would allow errors of omission among the relationships between the key concepts. The analysis of the close relationships, however, provided a first stage of understanding of the pattern ofthe professor's thinking in a course.

The tree structure for the law course was headed by the most important concept in the course which was common law methodology. This concept was the course goal and subsumed all other key concepts. The course pivoted, however, around the second and third most important concepts, liability for fault and recovery of damages which were the key concepts linked most closely. Analysis of their relationship showed it to be logical according to the taxonomy of relationships: recovery of damages is conditional upon liability for fault. Intentional tort, that is, intended wrongdoing, produces a kind of liability for fault, and therefore has a structural relationship, while it relates to recovery of damages in a conditional logical manner, that is, recovery of damages depends upon intentional tort. The tree structure in figure 1 shows that foreseeabilty rule, causation, damage and vicarious liability for fault relate to liability for fault and recovery of damages in a parallel manner, being subsets of liability for fault and determining whether there will be recovery of damages. The remaining two key concepts are mitigating concepts of liability for fault. Unintentional tort, or accident, would not be subsumed under liability for fault unless injury had occurred. Public policy could change or adjust a decision which would affect liability for fault. The pattern of relationships between key concepts in this course is particularly coherent, showing high regularity compared to the patterns found in other courses, which suggests considerable legal order.

This first stage of analysis provided a description of the dominant relationships in the course, and revealed an orderly pattern, but did not explain how or why the relationships had occurred. In order to more fully understand the deep structure of the concepts, three further methods of conceptual analysis were employed using the law course concepts.

Attribute analysis

Early research on concept formation was based on the assumption that concepts consist of a group of attributes (Bruner, Goodnow & Austin, 1956; Donald, 1963; Hovland, 1952). Determining which attributes were included in the concept was the process by which one formed a concept. The learner deduced a concept by comparing examples and non-examples of the concept which either had or did not have the correct values of a set of attributes. Tiemann & Markle (1978) applied this paradigm to the production of instructional materials. Their method involved taking the most typical or central definition of a concept, then isolating its properties to discover what was essential and what was not essential to the concept. For each essential property, or attribute, the question was then asked, "Is this property always the same or does it vary?" For example, for the concept antonym, the part of speech would be a variable attribute because nouns, verbs, etc. could be antonyms. A critical attribute was a property without which the concept would not exist. For example, to be an antonym, a word would have to have a meaning opposite to the meaning of some other word. If a change were made in a critical attribute, the result would be a non-example. Examples and non-examples were then created to display different values of the variable attributes.

This analytic framework was applied to key concepts in the courses in our study. Concept definitions provided by the professor and students had been coded to reveal what constituted an essential definition, according to the method used in the WAIS vocabulary subtest. The coding allowed for examination of what constituted the defining characteristics of the key concepts. The most common problem in establishing critical attributes was that of interdependencies found between them, since the method assumed that the attributes would be mutually exclusive or independent factors. One solution was to excise superordinate attributes, that is, those critical attributes for which a nonexample could not be found. For example, for the concept mythical creature, Tiemann & Markle found that there were no nonexamples of the critical attribute "product of human invention", but that it would apply to all mythological creatures. This attribute was then listed as a superordinate attribute.

A more serious problem with the method arose when an interdependency between the attributes of a concept was discovered which was not only superordinate but set a framework for that concept and others in the same course. For example, in the law course, for the concepts liability for fault and recovery of damages, several conditions obtained: there had to be a person, an act committed, and damages caused. The conditions constituted a set of relationships rather than a set of attributes. A problem of the opposite nature arose for other courses when the concepts within a course were compared based on the attribute analysis. Because each concept was analyzed independently, the critical attributes for related concepts did not reflect the inherent semantic relations between them. For example, in the course on the psychology of thinking the attribute analyses of language and symbolic system did now show parallel criteria, although the concepts are closely related in meaning. This had occurred because a consistent set of attributes had not been used in analyzing the concepts. Because of this lack of consistency, relationships between concepts were buried. To correct for these problems, we decided to broaden the framework of analysis and to focus on the set of generic features needed to categorize the concepts in a course (Bailin, in press). This set of features could be applied to individual concepts with the addition of differentiating or specifying features, yet would allow relationships between concepts to be discerned.

Feature analysis

The method of feature analysis consisted of five steps. To begin, the Wittgensteinian question was asked, "In what way is this concept used?" More operationally, the question was "What features does the function of this concept imply?" For example, in the concept liability for fault, there is a person who commits an act which causes damage to another person. The two persons, the act, and the damage are implied features, and the commission of the act and the causation of damage relate the features to each other.

Second, each feature was given a letter label (Figure 2). A feature was considered to be generic rather than specific, true on any occasion of use rather than on a particular occasion. Third, a short description of each feature was written referring to the feature by its letter label. Each description was identified as a numbered statement. Fourth, whenever possible, the relationships between features were stated in a numbered description. Fifth, whenever possible, consequences or applications of the concept were identified by a numbered description. The description and relation statements were used for as many concepts as possible. This method allowed the relationships between key concepts in a course to be elucidated although the set of features used in one course could not necessarily be applied to another one.

Application of the method to the law course revealed certain characteristics of the course not previously discerned. The number of descriptive statements ranged from six to ten, and were highly consistent across key concepts in the course (Figure 2). In fact, the first four statements were repeated in each of the feature analyses of the ten key concepts related in the tree structure. This shows a clear and tightly structured pattern of conceptualization in the course and suggests a higher degree of codification or regularity than the concept of common law, understood to be based on usage and custom, would suggest. A comparison of the feature analyses of the two pivot concepts in the course, liability for fault and recovery of damages, revealed the similarities and differences between them (Figures 2 & 3). The seven conditions of liability for fault were repeated for recovery of damages. The eighth descriptive statement, which was the consequence of the previous seven in liability for fault, became part of the features for recovery of damages. This reflects the relationship between the two concepts revealed in the tree structure: recovery of damages was conditional upon liability for fault in a logical relationship.

Thus the feature analysis of key concepts in the law course revealed a tightly structured, logically related set of concepts with a distinct set of central features: two persons, an act, and damage, which pertained to all key concepts in the course, except the superordinate concept, common law methodology. The regularity displayed in the tree structure was repeated in the feature analysis with two additions. First, each key concept had a small number of features specific to it which could be considered elaborations or qualifications of the pivot concepts. Second, a limitation of the tree structure was revealed by the analysis of the concepts unintentional tort and public policy. These concepts had been portrayed in the tree structure as adjunct to the main set of relations, but the feature analysis showed them to have a pattern similar to that of the other key concepts in the course, suggesting a more central role for them. Thus the feature analysis provided a more accurate specification of the relationships between key concepts in the course.

Could we expect the feature analysis of this course to provide a sufficiently elaborate or comprehensive pattern for retention and application? This question can be tested, but our investigation reveals that the analysis provides an abstraction, a skeleton of the operating conditions. It does not show the actual instances or cases in which the relationships between features occur and could therefore not be expected to provide a sufficiently elaborate instructional sequence by itself. It could well, however, act as a synthesizer for such a sequence. In conjunction with a set of cases, it would provide an organizer and an operational definition which would effect closure of meaning, and thereby curtail ambiguity.

Network analysis

Network analysis is the analysis of the structure of relations among the components in a given domain. In the social sciences a network is defined as a specific type of relation linking a defined set of persons, objects or events (Mitchell, 1969). The set of persons, objects, or events may be called actors or nodes, and possess an attribute or attributes in common (Knoke & Kuklinski, 1982). The configuration of present and absent relations among the nodes reveals a specific network structure which may vary from loosely to tightly linked and from hierarchical to cluster to linear in form. It is assumed that the structure of relations among nodes and the location of the nodes have important consequences both for the individual units and for the system as a whole.

The application of network analysis to knowledge structures should, then, not only allow the relationships between concepts to be studied but should also suggest consequences or strategies deriving from the structures. The tree structure was a crude form of network which allowed the relationships between dominant concepts or nodes in the course to be examined. The structure of relations between concepts suggested learning strategies. For example, in courses displaying tight, hierarchical conceptual tree structures as in the physics course, it would be expected that learning would be an all-or-none phenomenon, with the structure itself assuming importance in the learning process. Where a course was structured in a cluster formation with central pivot concepts it would be expected that the pivot concepts would be critical for success in the course. For loosely linked concept structures, one would expect knowledge of the individual concepts to be more important than the structure itself for learning.

A coherent conceptual network could be developed from the feature analysis of individual key concepts, showing the relationships between features of the concept. In the network produced by this method, relations between nodes varied, however, creating a closed diagram of some complexity. The diagrams created by this method clearly showed the components of the concept and their relationships. Figure 4, the conceptual network of liability for fault, is shown to consist of three nodes connected by directed lines, revealing the contingencies within the concept. The consequence of the concept is then diagrammed outside the box but connected the box but connected to it by the contingency link "then". In comparison with the conceptual network diagrammed for liability for fault, that for recovery of damages is shown to be complete within itself, that is, not having external consequences (Figure 5). This reflects the form of the feature analysis and also its logical relationship to liability for fault. Figure 5 also reflects the two situations which may pertain by means of two boxes. The conceptual networks as diagrammed show more clearly the kinds of features and relations that constitute each concept. The similarities and differentiating features also assume prominence, providing a highly salient explanation of concepts in the course and how they relate.

The additional instructional value of this method of portrayal could be expected to be clearer presentation of features and relationships with an equivalent reduction in ambiguity. This method should meet the criteria postulated by Reif (1983) for interpreting a concept by means of procedural specifications and independent variables or conditions but examples would be required to specify concept values. The methods of feature and network analysis described here thus fulfill two of the three major procedures for specifying a concept. With the addition of examples, the products of these analyses could be expected to provide a sufficiently coherent elaboration to ensure meaningful and retrievable learning.

In summary, it is possible to develop and compare methods of portraying knowledge structures on the basis of their instructional consequences. Earlier methods such as tree structures and semantic analysis revealed certain aspects of instructional domains and explained learning difficulties in the content area. More refined methods offer the possibility of elaborating a concept so that its constitution can be understood. Conceptual networks based on feature analysis hold the promise of coherency and thus of acting as synthesizers or conceptual organizers which should reduce ambiguity and error in learning.

Table 1

Taxonomy of Relationships Between Concepts

Similarity Relationships

associative: concepts are contiguous or descriptive of each other	- liberalism and pluralism (history) - noise and critical band (physics)
functional: concepts have a similar outcome or purpose	- long term memory and schema (psychology) - morality and virtue (english)
structural: concepts have a taxonomic or hierarchical relationship such as a subset, inclusion, or kind or parts relationship	- liability for fault and vicarious liability (la - central processing and long term memory (psychology)

Dependency Relationships

procedural: concepts are ordered or sequenced as for steps, progression or prerequisites	- experimental techniques and analysis of data (biology) - vibration frequency and superposition of waves (physics)
logical: concepts have a logical or conditional order	- liability for fault and recovery of damages (la - industrialization and labor (history)
causal: concepts have an explicit cause-effect relationship	- flight and success of insects (entomology) - migration and urbanization (history)

Common Law Methodology

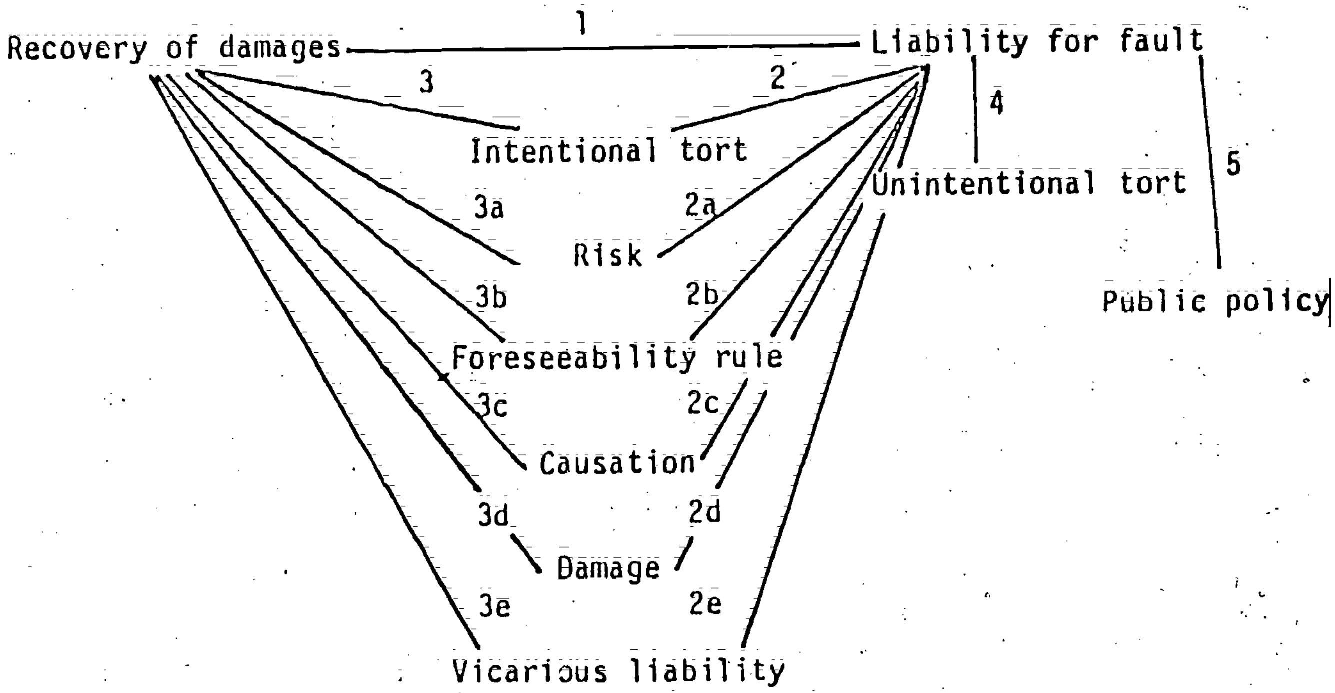


Figure 1. Tree Structure of Law Course

If *x* is liability for fault then:

if (i) there is a person *y*

(ii) there is an act *z*

(iii) *y* commits *z*

(iv) there is damage *a*

(v) there is a person *w*

(vii) *y* is at fault

then

(viii) *w* can recovery damages for *a* from *y*.

Figure 2. Feature analysis of liability for fault.

If *x* is recovery of damages then:

(i)	there is a person *y*
(ii)	there is an act *z*
(iii)	*y* commits *z*
(iv)	there is damage *a*
(v)	there is a person *w*
(vi)	*z* causes *a* to *w*
(vii)	*y* is at fault
(viii)	*w* recovers damages for *a* from *y*

OR

(ix)	if there is a person *b* such that *b* is vicariously liable for *z*, then *w* recovers damages from *b*

Figure 3. Feature analysis of recovery of damages.

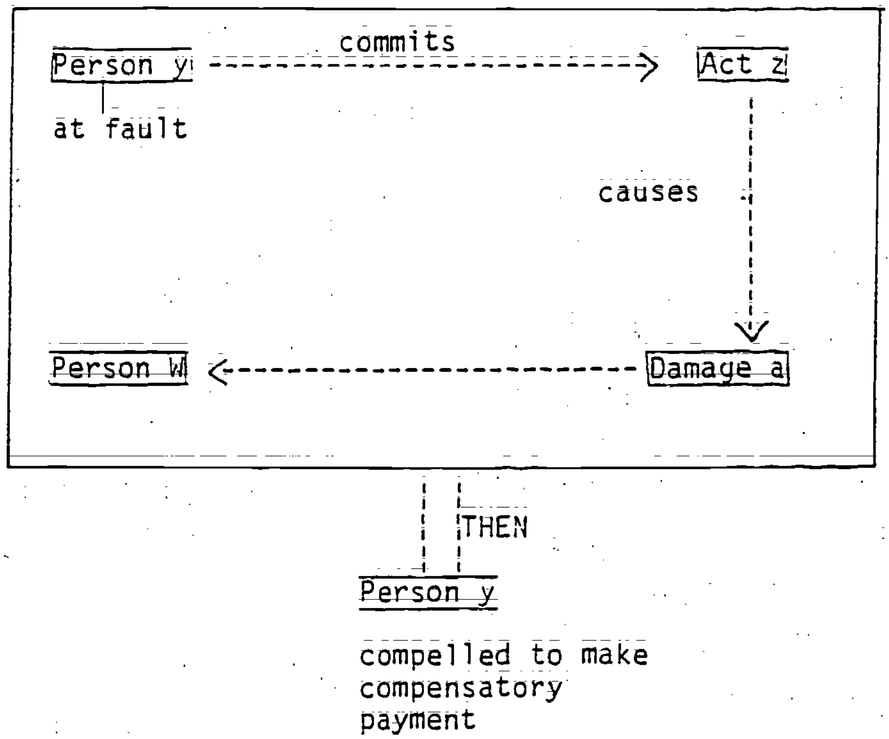
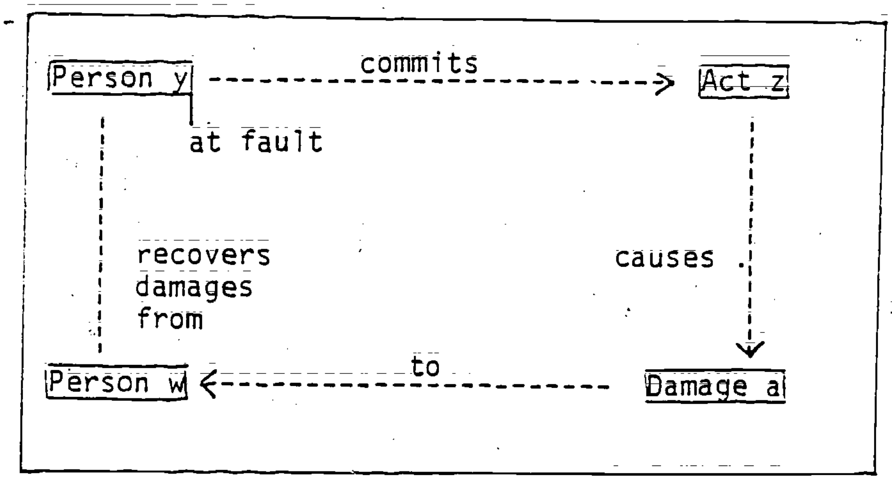


Figure 4. Conceptual network of liability for fault.



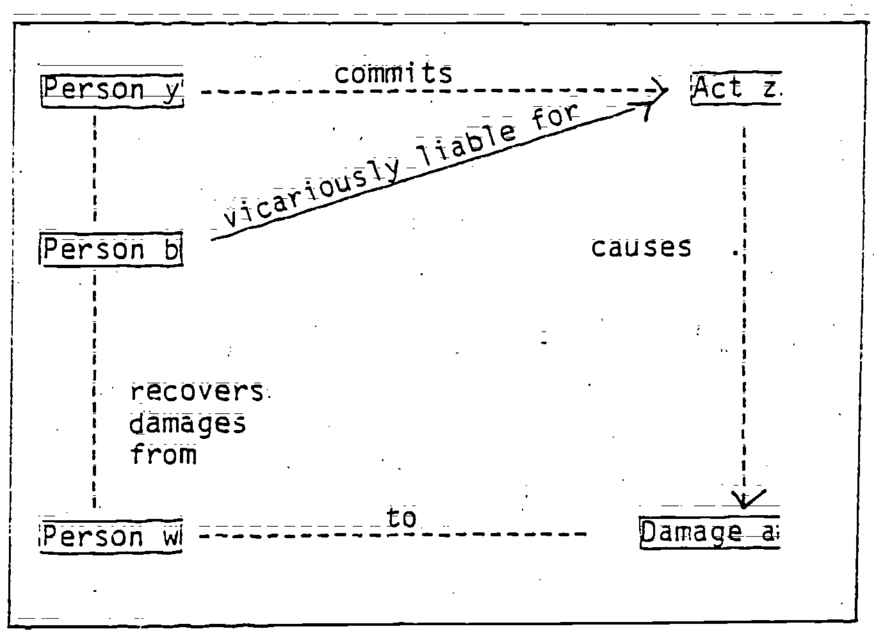


Figure 5 Conceptual networks of recovery of damages.

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