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Using an Artificial Intelligence-Based Argument Theory to Generate Automated Patient Education Dialogues for Families of Children with Juvenile Idiopathic Arthritis

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Abstract

Juvenile Idiopathic Arthritis (JIA) is the most common chronic rheumatic disease of childhood, with outcomes including pain, prolonged dependence on medications, and disability. Parents of children with JIA report being overwhelmed by the volume of information in the patient education materials that are available to them. This paper addresses this educational gap by applying an artificial intelligence method, based on an extended model of argument, to design and implement a dialogue system that allows users get the educational material they need, when they need it. In the developed system, the studied model of argument was leveraged as part of the system's dialogue manager. A qualitative evaluation of the system, using cognitive walkthroughs and semi-structured interviews with JIA domain experts, suggests that these methods show great promise for providing quality information to families of children with JIA when they need it.

Keywords:

Patient Education, Artificial Intelligence, Semantic Web

Introduction

Juvenile Idiopathic Arthritis (JIA) is a chronic rheumatic disease with clear physical and social burdens for those with the condition—and is also known to cause an "emotional rollercoaster" for affected families [1]. Appropriate patient education has been shown to reduce some of these burdens and improve quality of life [2]. Nevertheless, caregivers of children with JIA in Canada have expressed being overwhelmed from the myriad of information sources available to them [3]. Indeed, best practices in patient education call for giving caregivers control over what content they view [4]. Moreover, there seems to exist a strong preference towards education information from trusted sources, such as healthcare providers or the Arthritis Society [3]. Thus, there is a clear need to provide *trusted* patient educational content to (families of) children with JIA, which is not overwhelming and delivers content control and access to the information outside of clinic.

Dialogue systems are automated efforts to imitate a person-to-person communication style to make the interaction with a computer system more intuitive for the user [5]. Unlike traditional verbal and printed patient education mediums, dialogue systems are accessible via computers or mobile phones at the user's convenience. The key feature of dialogue systems is the flexibility of access to the educational content, as the user controls the subject of inquiry. This is unlike paper-based Patient Education Materials (PEM) or static websites, where the information is prepackaged. While dialogue systems have been only sparingly used for patient education, it has been reported that this educational medium results in a significant improvement in knowledge [6] and self-management [7]. Two types of dialogue are relevant to patient education—i.e., information seeking dialogue, where the aim is to provide information to answer a user's question; and inquiry dialogue, where users seek to explore and verify evidence [8].

An AI-based argument theory, based on the Toulmin model of argument, provides a useful model to represent educational content for a dialogue system. Argument theory offers a set of information representational constructs to represent the central elements of any dialogue, such as the dialogue's claim, the evidence backing the authenticity of the claim, the data used to derive the evidence, certain exceptions to the claim and so on. Toulmin's argument model, therefore, supprts the functions of language that are used to justify a claim in terms of a narrative structure that mimics a dialogue [9]. Therefore, there is a case for using argument theory to develop dialogue systems for patient education, as not only are dialogue systems more friendly and intuitive for educational purposes, but they also provide information that is backed up by evidence and can be further investigated for alternative options and/or additional details. Toulmin's model has been used by patient education tools, albeit for question-answering as opposed to a dialogue that manifests a series of follow-up questions [10].

Our objective is to investigate the use of argument theory to model the JIA educational content so it can be delivered via a dialogue system—with the goal of addressing the educational needs of families of children with JIA. Given the requirements of the JIA patient education materials, we leverage the *Extended Model of Argument* (EMA) [11] since it encompasses the diversity of topics and forms of information found in JIA PEM. Using the EMA, we developed an interactive dialogue based JIA patient education system—i.e., the Juvenile idiopathic Arthritis Dialogue-based Education (JADE) system (see Figure 1). In this paper, we present our knowledge management approach to develop JADE [12]. We discuss (**i**) the formulation of an ontology-based EMA knowledge model to formally represent the concepts and relationships underlying (extended) argument theory, resulting in the *JADE Ontology* (JO); (**ii**) the abstraction of relevant education themes from the available PEM, using thematic coding; and (**iii**) computerizing the PEM content, alongside the identified themes, using the JO. JADE has been developed and it contains 32 PEM covering 16 topics, in terms of 931 arguments. We developed semantic web-based reasoning methods to reason over the PEM content, represented using the JO, to formulate an interactive dialogue where the user can ask an initial question, as well as a series of

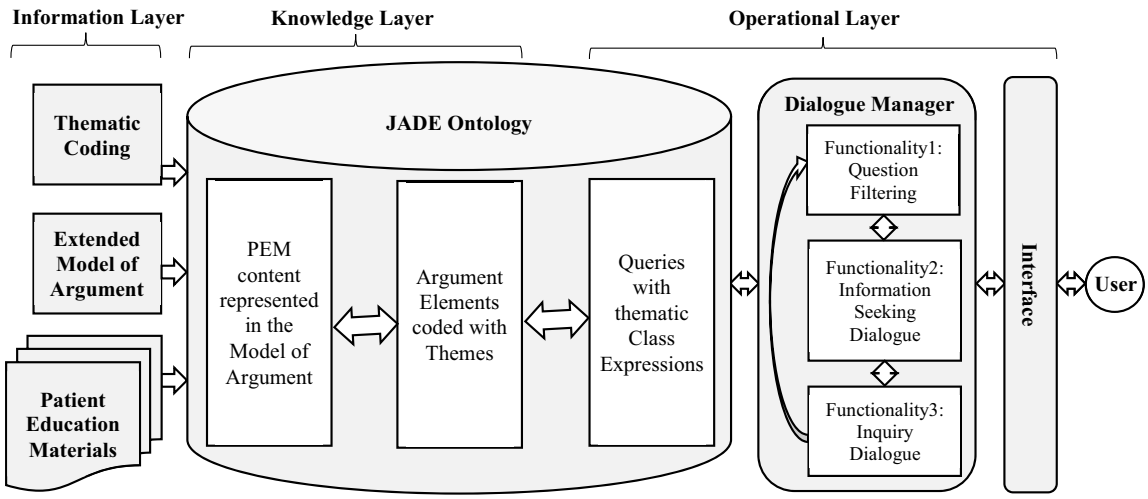

Figure 1– Architecture of the JADE system

follow-up questions. In this way, JADE provides families of children with JIA access to trusted PEM content approved by their healthcare providers—in a way that gives users control over the educational content that they are presented. JADE has been evaluated for content completeness, relevance, and utility.

The novel aspect of our patient education approach is the provision of a dialogue that is dynamically generated (in response to a variety of user queries) by selecting relevant arguments encoded in the JO and chaining a series of arguments using reasoning. According to the literature, one other dialogue system has used the Toulmin model of argument [10], however it is clinician facing and can only respond to a single question with content from a single argument.

JADE Architecture

Figure 1 depicts the 3 layers of the JADE system's design:

1. The information layer contains the EMA, thematic codes, and PEM content described previously [11]. This layer provids the knowledge model which is used to represent the PEM content in the JO.
2. The knowledge layer is comprised of the PEM content, coded to the EMA and thematic coding, represented in an ontology. This layer creates a computerized structure which the operational layer can draw on to provide an interactive dialogue. Thematic coding links individual EMA elements to an initial user question and the relationships between EMA elements, and individual arguments, allow for follow up questions about the content of the initial response.
3. The operational layer is made up of potential user questions encoded in the ontology, the dialogue manager, and the user interface. The dialogue manager receives the user's input through the interface and interacts with the ontology to formulate and deliver responses. It allows the user to find and select questions that are of interest to them, to have an information seeking dialogue by asking and receiving answers to their questions, and to participate in an inquiry dialogue. The latter uses question prompts based on the EMA and the chaining of arguments to help the user navigate through the PEM content.

Methods

The EMA serves as the knowledge model for integrating PEM content into the JADE system and is used to structure the inquiry dialogue it provides. Based on the Toulmin model, which contains 6 constructs: the claim, qualifier, data, warrant, backing, and rebuttal (renamed exception) [9], the EMA's 7 elements represent the parts used to justify a statement [11]:

1. The Claim is the statement being justified.
2. The Qualifier denotes the strength of the claim.
3. The Data represents situations where the claim is true.
4. Warrants, either explicit or implicit, explains how the data relates to the claim.
5. Exceptions are situations where the claim is not true.
6. Elaborations give more information about another element, for example a definition.
7. The Backing is the source of the information.

Thus, the following argument from the pamphlet: 'Using Ice and Heat at Home' (backing) can be coded to this model as follows: 'Some pinking of the skin is normal (exception), however, ice should be removed (claim) if the skin becomes pale and/or pain is felt (data) as this is a sign that skin damage due to cold is beginning (explicit warrant). As well, periodic skin checks are recommended (elaboration to the claim).' This knowledge model was formalized as the JO using Protégé 5.0.0 (Stanford University, 2016). Since the strengths of ontologies include reusability and extendibility, we have based the JO on Vitali and Peroni's Argument Model Ontology [13].

PEM Topic Identification

Thematic coding of the PEM content was used by the JADE system to filter questions, so users can ask about what interests them, and to locate relevant PEM content in the ontology in response to a user's question. Themes were generated inductively from the PEM content using grounded theory [14]. For example, the element 'periodic skin checks are recommended' was coded as *Periodic* and *Skin checks* during open coding. Selective coding merged *Skin checks* with similar codes into the *Monitor* code. *Monitor* and codes such as *Use treatment* were then grouped under the theme *Recommendation* during axial coding.

Knowledge Formalization

The JADE system requires a structured repository of domain specific content, so that it can be accessed by the dialogue manager to formulate responses to user's questions. For this purpose, the PEM content and linked thematic codes were computerized using the JO. The ontology has 4 top-level classes depicted in Figure 2 and described in detail below.

Individual arguments are represented as instances of **the 'ArgumentAsRepresentedByImplicitWarrant' (ARIW) class**. Since two or more arguments could share the same data element, i.e. have the same situation for which a claim is true, such as taking a certain medication, the data element was not unique. Neither was the claim element, as two or more arguments could share the same conclusion, for example, the recommendation to use a treatment. The implicit warrant, usually expressed as 'If Data, then Claim', was unique for all arguments.

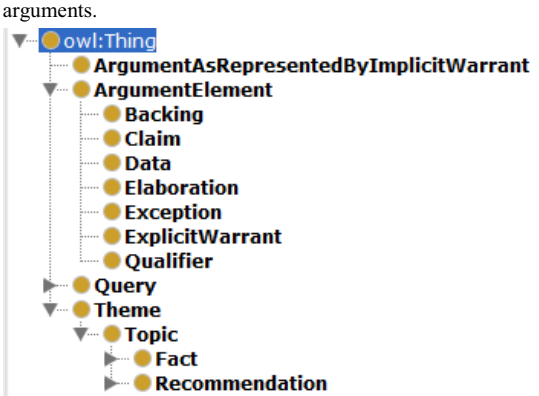

Figure 2– Top-level classes of the JADE ontology

The ArgumentElement class represents the 7 elements of the EMA, which are encoded individually as subclasses. PEM content, coded to the argument elements, was represented as instances of the coded element. For example, the argument: *If using heat and your child's skin turns red* (data)*, although some pinking of the skin is normal* (exception)*, then remove the heat source* (claim) from the pamphlet 'Using Ice and Heat at Home' (backing) was represented in the ontology as five instances: one each of the claim, data, exception, backing, and ARIW classes. Relationships between elements were encoded using object properties as shown in Table 1. Arguments were theoretically chained together when the claim of one argument contained the same content as an element of another argument. For example, the exception in: *There is no cure for JIA* (claim) *although there are medications that can reduce the inflammation and relieve the pain and swelling* (exception), is a claim in another argument: *If you have* JIA (data) *there are medications that can reduce the inflammation and relieve the pain and swelling* (claim). These links needed to be represented in the ontology, so we reused the 'sameAs' object property to link two elements of different arguments that contain the same content.

The Query class represents the questions users of the JADE system require to enter the network of PEM content encoded in the ontology. Individual questions were represented as subclasses of the Query class and were generated inductively from the PEM content. For example, PEM content describing the side effects of methotrexate, a medication used to treat JIA, induced the question: 'What are the side effects of methotrexate?'.

Each Query subclass has a class expression which attempts to translate the English question into a syntax the ontology reasoner can understand. For instance, the question above was expressed as the class expression:

(HasTheme some 'Side effects') and (IsElementOf some (HasElement some (HasTheme value Methotrexate))).

This tells the reasoner to find an argument element instance that has an instance of the 'Side effect' theme and is part of an argument in which an argument element has the theme 'Methotrexate'. The class expressions were written in the format of looking for one topic theme, or class of themes, that describes the subject of the query and one or more themes, or classes of themes, present in the argument describe its context. In the previous example, the topic theme was 'Side effects' and the context theme was 'Methotrexate'.

Table 1– The domain and range of the ontology object properties with inverse properties in brackets

Domain	Object Property	Range
Theme	DefinesThematically (HasTheme)	Argument-Element
Argument-Element	IsElementOf (HasElement)	ARIW
Backing	Backs (HasBacking)	ARIW
Elaboration	Elaborates (HasElaboration)	ExplicitWarrant, Data, Claim, Exception, Elaboration
Exception	Excepts (HasException)	Claim, Data, ExplicitWarrant, Elaboration
Qualifier	Qualifies (HasQualification)	Claim
Explicit-Warrant	Requires (HasRequirement)	Data
Data	Supports (HasSupport)	Claim
Explicit-Warrant	Warrants (HasWarrant)	Claim
Explicit-Warrant	HasAdditionalWarrant	ExplicitWarrant
Claim	sameAs	Argument-Element

The Theme class represents the thematic coding of the PEM. The codes are represented with a hierarchy of subclasses with the leaf codes as instances. For instance, the theme 'Liver damage' is an instance of the class 'Side effects' which is a subclass of the class 'Fact' that represents the context of a user's situation. The object property 'DefinesThematically' linked the instances to the argument elements they were coded to.

To date, 351 arguments extracted from the PEM have been instantiated as argument elements in the ontology. These arguments were prioritized as they were directly relevant or adjacent to topics covered in the scenarios used in the evaluation, which will be described further below. They represented most of the structures i.e. journal articles and pamphlets, topics i.e. treatments and etiology, and formats i.e. lists and images. Thus, this was a representative sample of the arguments extracted from the JIA PEM.

JADE Functionalities

The JADE system was designed with 3 functionalities:

1. A question filtering system offers a way to choose interesting questions that fit their situation.
2. An information seeking dialogue provides quality information from PEM in response to user's questions.

3. An inquiry dialogue allows users to explore the PEM content to determine whether the information provided was trustworthy and relevant to their situation.

Functionality 1: There are currently 163 questions encoded in the ontology. This functionality uses the thematic codes and class expression format to allow users to screen these options for the questions they want to ask. A user selects from a list of themes to find questions looking for: 'Recommendations about Methotrexate and DrinkingAlcohol', yielding 1, namely: 'Can I drink alcohol while taking methotrexate?'.

Functionality 2: By choosing a question, the user engages the information seeking dialogue functionality. This functionality uses the thematic coding represented in the ontology to deliver relevant content from PEM in response to user questions. Each question represents a query subclass and its class expression. The reasoner locates argument elements from the ontology that fit the class expression. In our example, the claim: 'it is best to avoid alcohol' is located because its themes are 'Drinking alcohol' and an instance of the Recommendation class and its data HasTheme 'Methotrexate'.

Question prompts for the inquiry dialogue functionality are also generated here according to the object properties present in the argument of the located element. In our example both HasWarrant and HasBacking properties are present in the located claim's argument. Thus, the full dialogue system response as per our example is:

If taking methotrexate, then it is best to avoid alcohol.

Want to know the reason for this?

Want to know the source of this?

Functionality 3: By choosing a question prompt the user can engage in an inquiry dialogue and explore the PEM content surrounding the answer to their question. The inquiry dialogue functionality leverages the object properties between argument elements, derived from the EMA, to create question prompts the user could use to explore and verify information from the PEM. To continue our example, the user chooses the first prompt: 'Want to know more about this?'. In response, the dialogue system locates the relevant argument element(s) in the range of the object property associated with this prompt, i.e. HasWarrant. This locates the explicit warrant: 'Taking methotrexate and drinking alcohol could harm your liver'. As in functionality 2 question prompts are generated. Although, in this functionality only object properties for the argument element in question, not the entire argument, will be used. The entire response as viewed by the user is:

Taking methotrexate and drinking alcohol could harm your liver.

Want to know the reason for this?

From here the user can use the home button to return to the question filtering of functionality 1, or the back button to return to the information seeking dialogue of functionality 2, or a question prompt to continue with functionality 3.

Evaluation Study

The JADE system was qualitatively evaluated to determine whether its responses were complete, relevant, accurate, and understandable. We aimed to recruit 5-8 healthcare providers from the IWK Pediatric Rheumatology Division for their expert domain knowledge of JIA and familiarity with the PEM content used in the dialogue system. Participants completed a cognitive walkthrough of the dialogue system followed by a semi-structured interview. Cognitive walkthroughs involved the participants verbalizing their thoughts as they interacted with the dialogue system, guided by a scenario and set of tasks [15]. The interview questions were based on the content portion of the O'Grady framework for evaluating interactive applications [16]. Screen capture and audio recordings of the evaluations were analyzed qualitatively using directed content analysis, with the O'Grady framework used as predetermined codes [17]. Approval for this study was given by the IWK Research Ethics Board (approval #1023261).

Results

6 clinicians have participated in the evaluation study: 4 nurses and allied health professionals and 2 pediatric rheumatologists. Two had less than 5 years of experience working in the pediatric rheumatology division, 3 had between 11 and 20 years of experience, and one had more than 20 years of experience. Three claimed to be very comfortable with computers, 1 was moderately comfortable, while two were moderately uncomfortable. Three reported that more than 75% of their clinical encounters involved using PEM, while 3 reported less than 40%.

Eight major themes were identified during analysis. Themes were determined to be major if 40% or more of participants had responses categorized under that code. Saturation was achieved, as evidenced by the fact that no new codes were added after the third evaluation. The major themes are listed below with examples of quotes from participants.

1. Positive responses to the JADE system.

   Participant 6: Having that data…available like this is really exciting!

2. Content was largely accurate outside of some inaccuracies in the PEM.

   Participant 4: [There was] nothing that was incorrect.

   Participant 3: [This PEM is from] 2011, yikes, that'll be from before some of these kids were born.

3. Content was credible but could be improved through better presentation.

   Participant 1: [Having links to the sources] is going to be really helpful.

   Participant 4: For instance, if you have a [hospital] logo… that tends to increase folk's credibility.

4. Content was mostly relevant, with a few exceptions.

   Participant 4: I think it's really relevant to what the patients and families are experiencing.

   Participant 5: Interesting, because I clicked on [a question about] 'ice' and then it starts talking about 'heat' [when I click on a question prompt].

5. Content was mostly complete, with a few exceptions.

   Participant 5: As you continued to 'want to know more about it' I think you did get all the information.

   Participant 3: Is there something about not getting live virus vaccines [while taking methotrexate]? One of your issues is going to be how are all the links set up, because they aren't a single linear link, its lots of things that end up being a complicated Gordian knot.

6. Individual responses were clear and consise, but a broader organization of the content was lacking.

   Participant 2: I think that's simple, to the point, uncomplicated.

   Participant 3: You have things that follow each other that are totally unrelated…with a big long list, people read the first two or three things and then they get bored and miss stuff.

7. Awkward wording occasionally made the information unclear.

Participant 5: 'What does that describe?' ... It's a bit awkward.

8. Accessibility issues to the JADE system.

   Participant 4: This is very much geared towards users that have the ability to be able to navigate it physically. Are there any parameters for folks who have limitations in terms of audio or visual?

Discussion

The results of the evaluation study show that the application of the AI-based argument theory method for delivering patient education dialogue was largely successful. The PEM content was fully integrated and formalized into the JO using the EMA and domain experts found the resulting dialogue content to have utility, outside of a few exceptions. The reasons for the few irrelevant, incomplete, and difficult to understand responses found during the evaluation are discussed here.

The majority of irrelevant or incomplete responses were due to gaps in the existing PEM. The remainder were caused by two issues with how the thematic coding and chaining between arguments were represented in the JO. First there was no representation in the JO of the causation of a side effect by a drug opposed to merely appearing in the same argument as the drug. Second, the sameAs property caused the reasoner to conflate the themes from two chained arguments, which should be separate, leading to irrelevant elements being selected during information seeking dialogue. Future work will address this by using alternate methods of representation.

The 6th theme of the evaluation shows the limits of the EMA, which does not contain constructs to model knowledge beyond the level of individual arguments. Thus, while the EMA and thematic coding have successfully represented a large portion of the knowledge contained in the PEM, another layer of representation is required. The relative importance and overall subject of each argument need to be modelled to organize the elements, relative to each other, in the system's responses. Future work will identify such a model and implement it.

We believe the remaining issues highlighted in the evaluation study, i.e awkward wording, accessibility issues, and credible presentation, can be best addressed in co-design with JIA stakeholders. Future work will therefore seek to engage families of children with JIA and their healthcare providers.

Limitations

The participants recruited for the evaluation study were from a single site and while their familiarity with the PEM used in the system was beneficial to the study it potentially limits the breadth of viewpoints a broader inclusion strategy could have offered. Similarly, the analysis of the results was performed by a single coder which increases the potential for bias.

While the methods used in this work are generalizable to patient education for other conditions, the substantial time and knowledge required, limits their applicability. The coder(s) must have a good working knowledge of the EMA as well as grounded theory for the thematic coding. They must also understand the condition described by the PEM and be able to represent the resulting codes in an ontology. The time needed to do this is an additional barrier to these methods being used.

Conclusions

This work describes a novel method of using a model of argument to create a patient education dialogue system for healthcare users. The evaluation of the JADE system showed that it provided responses that were mostly relevant, understandable, and complete, thus demonstrating its potential to address some of the current gaps in patient education experienced by families of children with JIA.

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