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Case Report

Design science research application in medical radiation science education: A case study on the evaluation of a developed artifact

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ABSTRACT

Design Science Research (DSR) combines quantitative and qualitative approaches for educational research. One of the critical steps of DSR is the evaluation phase. In this phase, the artifact's utility, fitness, and usefulness are noted and reviewed. Since the DSR applied to health science is limited, this paper aims to present the evaluation phase of a study that developed an artifact for training student radiographers in chest pattern recognition. The artifact which is described in detail elsewhere by Mdletshe et al. [1], was developed as a tailor-made solution in medical radiation sciences education (MRSE), using DSR. During the evaluation of the artifact, the System Usability Scale (SUS) was used for the quantitative evaluation of the artifact. Meanwhile, the qualitative approach was performed using a hierarchy of qualitative criteria based on a review of multiple sources. This study demonstrated the DSR key concepts of the evaluation phase applied to health science. The presented case will help to demonstrate the implementation of the evaluation phase in a research project in health sciences (MRSE).

RÉSUMÉ

La recherche en sciences de la conception (RSD) combine des approches quantitatives et qualitatives pour la recherche en éducation. L'une des étapes essentielles de la RSD est la phase d'évaluation. Au cours de cette phase, l'utilité, la pertinence et l'utilité de l'artefact sont notées et examinées. Étant donné que la RSD appliquée aux sciences de la santé est limitée, cet article vise à présenter la phase d'évaluation d'une étude qui a permis de développer un artefact pour former les étudiants radiographes à la reconnaissance des formes de la poitrine. L'artefact, décrit en détail ailleurs par Mdletshe et al. [1], a été développé comme une solution sur mesure pour l'enseignement des sciences de la radiation médicale (ESRM), en utilisant la RSD. Au cours de l'évaluation de l'artefact, l'échelle d'utilisabilité des systèmes a été utilisée pour l'évaluation quantitative de l'artefact. Parallèlement, l'approche qualitative a été réalisée à l'aide d'une hiérarchie de critères qualitatifs basée sur un examen de sources multiples. Cette étude a démontré les concepts clés de la RSD de la phase d'évaluation appliqués aux sciences de la santé. Le cas présenté permettra de démontrer la mise en œuvre de la phase d'évaluation dans un projet de recherche en sciences de la santé (ESRM)

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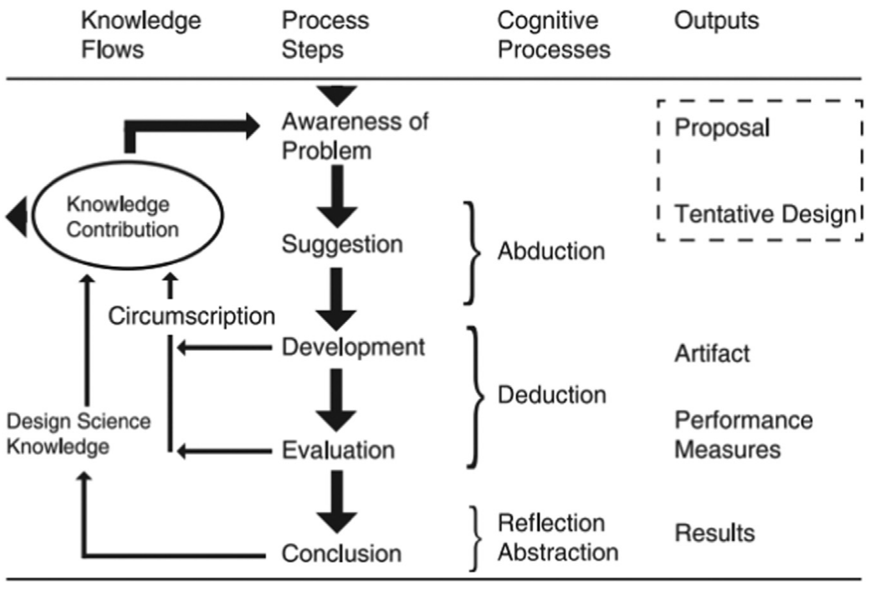

Fig. 1. A general methodology of DSR [3,6].

Background

Quantitative educational research analysis helps provide evidence-based recommendations, while qualitative analysis provides more description and perspective to aid understanding [2]. Design science research (DSR) combines both approaches to create an artifact and design theory to solve a specific problem [3]. An artifact in the context of DSR refers to artificial/man-made objects and phenomena that are constructed to meet specific desired goals and can be in the form of constructs, models, frameworks, architectures, design principles, methods, and/or instantiations [3]. DSR is generally used in information systems (IS); however, Hevner and Wickramasinghe [4] recently demonstrated an increased use of this paradigm in health sciences.

DSR allows exploration of multiple contexts, including educational, software design and clinical contexts, therefore an ideal platform for collaborative and multidisciplinary research. By its nature, DSR is pragmatic as it is more concerned with practical results than with theories and principles [5]. The DSR design is exploratory and is conducted in five critical process steps (Fig. 1), allowing one type of data to be collected at a time while creating the opportunity to design an instrument that can be measured/evaluated.

Since the essence of DSR design is to “build and evaluate,” the evaluation phase is a critical activity as *a)* it provides feedback for further development, *b)* assures the rigour of the research, and *c)* produces proof of an artifact’s relevance for practice [7–9]. The evaluation phase allows the combination of different paradigms since it can be conducted in a technical, interpretative, or positivistic manner [10]. Because various strategies can be used during evaluation, the researcher must ensure that the appropriate strategy is selected and justified for the artifact being designed in a given situation [9]. However, Venable et al. [11,12] highlight that current literature provides little guidance for researchers with regards to what to evaluate and which methods to use, why to evaluate/chose a particular method, when to use a particular method and how to maximize the benefits from the evaluation method/s used. Further, they state that most of the literature generally assumes that evaluation fundamentally requires one method to demonstrate the artifact’s utility, fitness, and usefulness while noting that different evaluations may be needed at various phases of the research process due to the cyclical nature of the DSR projects. The choice of the methodology used in conducting research should align with the research goal and available resources [13].

This paper presents a case study of evaluating an artifact for training student radiographers in chest pattern recognition (the ability to recognize normal anatomical and physiological appearances on an image/radiograph and the variations of those appearances which could indicate pathology). The artifact, which is described in detail elsewhere [1], was designed as a tailor-made solution in medical radiation sciences education (MRSE). In this paper, we focus on the evaluation of this artifact to further demonstrate how DSR can be meaningfully applied to MRSE.

Evaluation in the context of DSR

Before proceeding to the evaluation step, in this section, we briefly explain the meaning of evaluation as applied in this work. In DSR, evaluation is the systematic investigation of the artifact’s worth or merit, by demonstrating its utility, quality, and efficacy using rigorous ***quantitative*** and/or ***qualitative*** evaluation methods [12,14]. It can, therefore, be viewed as an analysis of the adequacy of the artifact’s design in which hypotheses are made about the behaviour of the artifact. Rarely in the DSR paradigm are initial hypotheses concerning behaviour wholly borne out. Instead, evaluation results and additional in-

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Table 1
System Usability Scale [15].

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1. I think that I would like to use this system frequently.	1	2	3	4	5
2. I found the system unnecessarily complex.	1	2	3	4	5
3. I thought the system was easy to use.	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system.	1	2	3	4	5
5. I found the various functions in this system were well integrated.	1	2	3	4	5
6. I thought there was too much inconsistency in this system.	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly.	1	2	3	4	5
8. I found the system very cumbersome to use.	1	2	3	4	5
9. I felt very confident using the system.	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system.	1	2	3	4	5

formation gained in the construction and testing of the artifact are brought together to provide feedback for another round of suggestions (refer to the circumscription arrows of Fig. 1).

Drawing from this understanding of evaluation, we describe below, how both the quantitative and qualitative approaches were used to evaluate the designed artifact.

Quantitative evaluation

One of the instrumental approaches to quantitatively evaluating an artifact is usability testing. Usability is defined as the general quality of the ***appropriateness to a purpose*** of any particular artifact i.e. the ease of using a product for a specific set of circumstances [15,16]. Significantly, usability testing focuses on systematically identifying usability problems at an early stage in the development process, which allows the rectification of challenges before the comprehensive implementation of the artifact [16].

The evaluation tool

For this project, the System Usability Scale (SUS), was used to quantitatively evaluate the designed artifact. As shown in Table 1 below, the SUS is a simple ten-item scale that gives a global view of subjective assessments of usability.

The SUS has been validated and used in different contexts outside MRSE and it is robust, reliable, and correlates with other subjective usability measures [15]. In addition, the SUS was the chosen tool for this project because it can be used on small sample sizes, as in this case, with reliable results. Moreover, it is easy to administer and it can effectively differentiate between usable and unusable systems. Lastly but importantly, a comment section can be included to enhance the meaning of the data gathered while allowing the participants to contribute to how the artifact could be improved.

The following principles and guidelines were used to analyze the data collected using the SUS [15]:

- The SUS yields a single number representing a composite measure of the overall usability of the system being studied. The scores for individual items are not meaningful on their own.
- To calculate the SUS score, the score contributions from each item are summed up. Each item's score contribution will range from 0 to 4 because the participants' scores for each question are converted to a new number. For items 1, 3, 5, 7, and 9, the score contribution is the scale position minus 1. For items 2, 4, 6, 8, and 10, the contribution is 5 minus the scale position.
- Multiply the sum of the scores by 2.5 to obtain the overall value of system usability. SUS scores have a range of 0 to 100.

A SUS score above 68 is considered above average and a score below 68 is below average. The scores that are obtained must be converted into a percentage using a process called normalizing because the raw SUS scores are not a percentage even though they have a range of 0 - 100 [17]. This process takes raw SUS scores and generates percentile ranks and letter grades (A+ to F) for eight different application types [17]. Normalizing is analogous to grading on a curve based on the distribution of all scores. Sauro (2016) goes further to give an example where a raw SUS score of 74 converts to a percentile rank of 70%. This SUS score of 74 has higher perceived usability than 70% of all products tested and is therefore inferred as a grade of a B-[17]. Fig. 2 is used to demonstrate the percentile ranks associated with SUS scores and letter grades.

Application of the SUS to evaluate the new learning artifact

Purposive sampling was used to select a sample of radiography educators who were involved in the undergraduate diagnostic radiography programmes that were offered in the study location at the time (these programmes included a 3-year diploma and 4-year bachelor's degree). Six out of seven (86% response rate) educators responded positively and participated in the evaluation of the artifact. Research suggests that 95% of

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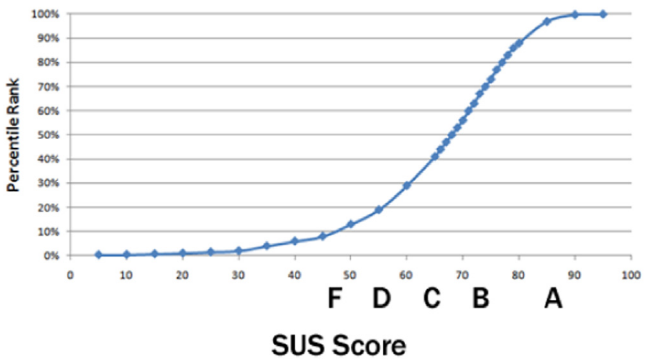

Fig. 2. Association of percentile ranks with SUS scores [17].

Table 2
SUS scores for participants (n = 6)

Participant number	Score
1	70
2	85
3	55
4	50
5	77.5
6	87.5
Average score	70.1

usability problems that will become apparent with wider implementation of a product can be quickly identified with only five or six randomly identified potential users [16].

The participants were given a brief description of the artifact prior to them using it. The SUS was administered immediately after the participants had finished using the artifact and they were encouraged to record their immediate response to each item without thinking deeply about it. The data analysis adhered to the guidelines for using the SUS [15]. The scores for each participant were calculated as shown in Table 2.

Overall, the artifact had good usability since the average score was >68 (=70.1). This raw SUS score of 70.1 converts to a percentile rank of 58%. It can therefore be inferred that the SUS score of 70.1 has higher perceived usability than 58% of all products tested using the SUS. This was deemed significant, and it was concluded that the artifact had good usability but could be improved. Based on the demographics of the participants considered with the SUS scores, it was concluded that neither their qualification nor age influenced how they experienced the usability of the artifact. Similarly, the age of the participants did not seem to have any influence on how participants experienced the usability of the artifact. The four participants who had scores above 68 all had a master's degree. Of the two participants with scores below 68, one had a bachelor's degree, and the other had a doctoral degree.

Of the two participants with lower than 68 scores, one was 29 years old while the other was 57. The participants who had scores above 68 had an age range of 37 – 56 years (mean age = 44 years). Notably, both participants who had scores below 68 had no experience in using any radiography teaching software package/s. This led to most of their selection of scores being neutral. This is important to note, as, during the actual testing, there was very little explanation of how the artifact functions and the participants had to learn the artifact as they used it. Lack of previous experience with the use of radiography education-related software, therefore, had a significant contribution in terms of how the participants experienced the usability of the artifact, i.e. participants with no previous experience of using radiography education-related software had lower SUS scores. Among the comments made by the participants who had scores below 68 were the following:

- *"I found that the system could need a guide in order for the user to understand. I was a bit confused at times."*
- *"Well, difficult to comprehend full functionality as some buttons/functions not yet working – the same comment applies to integration question."*

The participants made several comments (in addition to the two highlighted above) concerning how they experienced the artifact's usability, and these are summed up below.

Affirmative comments

- *"I think this can work beautifully as a blended strategy where it is part of the battery of approaches – especially the function where students can be off-campus and request the facilitators' help."*
- *"I would be very excited to use this as a scaffolding strategy in simulation education."*
- *"I think it is simple enough to use, and I love the 'home' button if the user needs an easy way to go back."*
- *"I enjoyed using the artifact, I did not require too much time to understand how the artifact works; however, I do feel that using the artifact's different functions will take some time to understand, especially how the different filtering may enhance the image or be beneficial to pattern recognition. But this will come with use and practice using the artifact."*
- *"Well done!"*

Negative comments

- *"The drawings of the arrows and circles were not user-friendly."*

Suggestions/questions for future improvements

- *"Can students also discuss among themselves if they are in different locations?"*
- *"I would like a measurement tool function."*
- *"I just found that if the screen is bigger, it would be easier to use"* (NB: Usability testing was done using a standard laptop; hence this suggestion of the need to use a bigger screen)

These comments by the participants were helpful as they highlighted what worked well, what the challenges were, and

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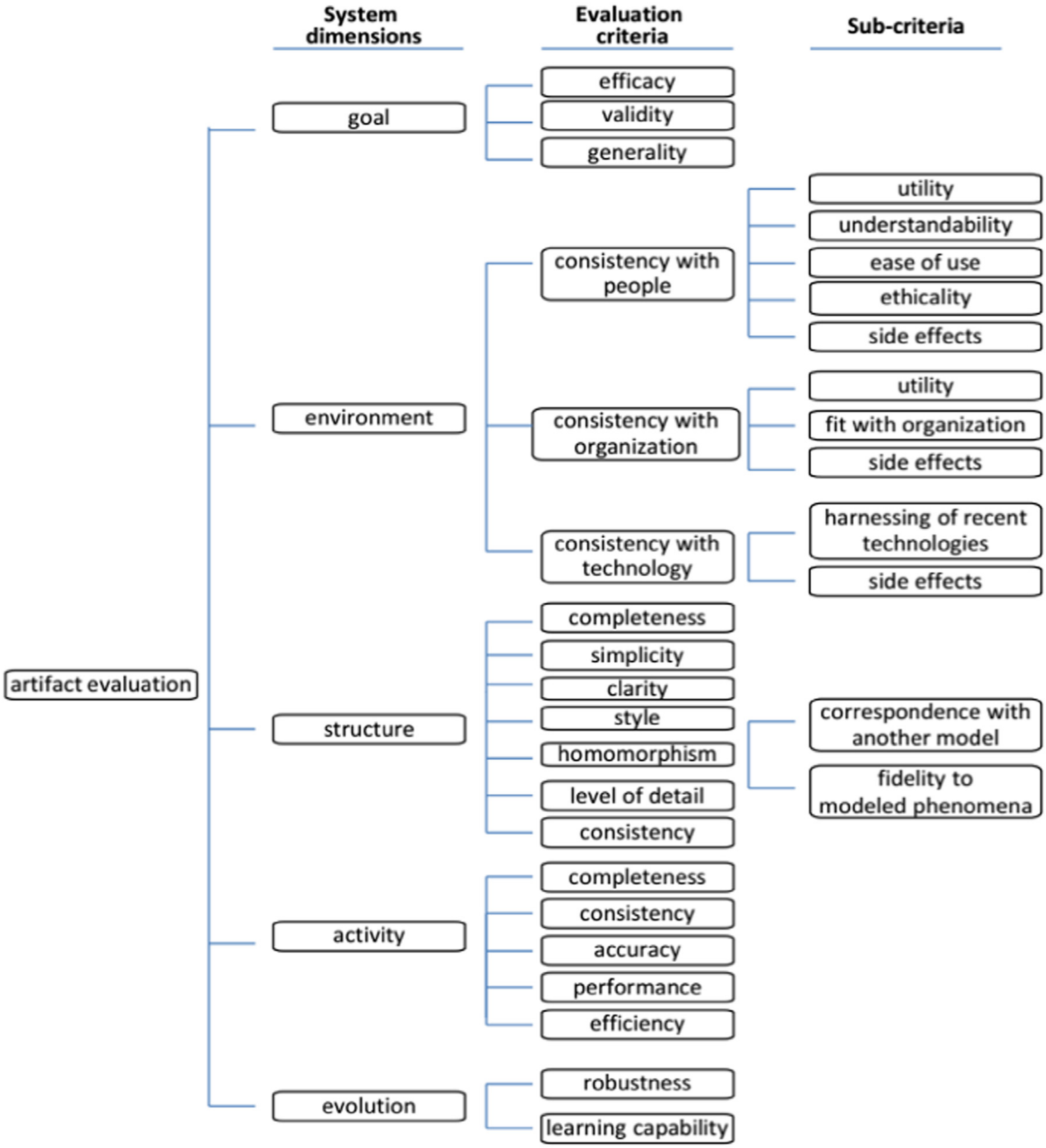

Fig.3. Hierarchy of qualitative criteria for IS artifact evaluation [5].

what could be done in the future to enhance the artifact before it is implemented widely. This is one of the most important values of quantitative evaluation of an artifact as it yields comments that could be used for the improvement of the artifact.

Qualitative evaluation

Prat *et al.* [5] propose a hierarchy of qualitative criteria (Fig. 3) based on a review of multiple sources that describe the evaluation approaches in DSR.

Within this model, some criteria (e.g. completeness, consistency, etc.) appear in more than one system dimension and may not need to be explored in detail within all system dimensions. The evaluation presented here focused on the goal, environment, and structure dimensions due to their significance [5], and to demonstrate how these are applied in context.

System dimension: goal

Prat *et al.* [5] state that the goal dimension is characterized by efficacy, validity, and generality. To have a clear grasp of the goal dimension, a reflection on the questions that informed the study is essential and practical. In the context of the case study being presented, these questions were:

- Can the use of a custom-designed artifact enhance the implicit skills of students in a radiography training programme in terms of pattern recognition skills?

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- If such a tool is designed, can it provide feedback to students and enhance authentic and independent learning by students while still allowing them to pace their learning?
- Can such an artifact be adapted for multiple systems/regions in the body?

The evaluation of the goal dimension was therefore **absolute** (whether the artifact achieves its goal) without comparing it to others since there were no known similar artifacts designed within the same environment with similar goals.

Criterion 1: Efficacy - efficacy is the ability to achieve the desired goal or intent, in the DSR context, it refers to the degree to which the artifact achieves its purpose [5]. In the case study research, efficacy was partially achieved with the design of the artifact, due to the limitation that the artifact could not be implemented for testing among students. Therefore, the efficacy of enhancing the pattern recognition skills of radiography students could not be corroborated.

Criterion 2: Validity - in the context of the DSR paradigm, Prat et al. [5] and Gilliland [18] view validity as the degree to which the artifact works correctly and achieves its goal. In the case study being presented, the artifact had limitations for wide implementation, however, the findings presented an accurate and trusted view of research events. This was a vital aspect as it is vital to understand why an artifact works or does not work to support future developments [19]. It was within this criterion that aspects that limited the implementation of the artifact were identified while highlighting the research contribution of the study.

Criterion 3: Generality - in DSR artifact evaluation, artifact generality refers to goal generality [5]. DSR as an approach allows for generalizing the artifact as a context-specific solution while contributing to the existing knowledge base [10]. Prat *et al.* [5] stress that when the artifact addresses a broad goal, it is considered to have a higher degree of generality. In the current case study, the artifact contributed to the knowledge base by generating new information, and the adopted design principles can be applied to other anatomical areas. Therefore, the artifact addresses a broad goal (good generality) and thus can be generalized for development to be used in other anatomical areas.

System dimension: environment

The environment criterion is about verifying the consistency of the designed artifact with people, organization, and technology [5], and can be classified in terms of an inner and an outer environment [3]. The inner environment has to do with components that make up the artifact (the organization of the components). In contrast, the outer environment has to do with the external forces and effects that influence the artifact.

Criterion 1: Consistency with people - within this criterion, the following sub-criteria was considered for the artifacts evaluation [5]:

- **Utility** measures the quality of the artifact in practical use. The evaluation of the artifact using the SUS (described previously), demonstrated consistency with people since the participants expressed a positive experience of the artifact. However, since the evaluation was not done among the students (the original intended audience) because it was not ready for broader implementation, the utility criterion could not be conscientiously evaluated.
- **Understandability** of the artifact refers to the ease of use. In the current case study, understandability demonstrated indicated consistency with people based on the above-average score of the SUS evaluation.
- **Ethicality** relates to ethics i.e., accepted principles of wrong or right conduct. In the context of the case study, the artifact was designed within ethical confines according to the ethical clearance given, further, the artifact had no perceived ethical issues.
- **Side effects** refer to undesirable secondary sequels, and the current case study had no perceived undesirable secondary sequels.

Criterion 2: Consistency with the organization - this relates to the alignment of the artifact with the organizational environment [5]. In the current case study, the artifact design was consistent with the organization as it sought to contribute positively to the strategy of the organization where the study was conducted, and the design was supported by the availability of relevant software licensing e.g., Microsoft SQL licensing.

Criterion 3: Consistency with technology - this refers to the harnessing of recent technologies [5]. In the context of the current case study, the artifact's design aligned with recent technologies as it sought to develop a new function based on the new technologies.

System dimension: structure

As shown in Fig. 3, Prat et al. [5] present the aspects that are evaluated in the structure criterion as follows:

Criterion 1: Completeness - completeness is about the artifact's ability to satisfy the requirements and constraints it was designed to solve [5]. During the evaluation, the artifact is therefore scrutinized for its ability to satisfy these requirements which are generally based on the specifications requirements document. In the context of the current case study, the artifact demonstrated completeness as it satisfied most of the requirements and constraints that were prescribed for the artifact.

Criterion 2: Simplicity - this refers to the state, quality, or instance of being simple, a concept supported by Aier and Fischer [19] who highlight those design theories should be simple to be easily understandable and manageable. The artifact must therefore be designed to be simple to understand and use. In the current case study, the artifact could be used without any guidance from the researcher. This was corroborated by the SUS test results which demonstrated that the artifact was adequately designed.

Criterion 3: Homomorphism - homomorphism has to do with the correspondence of a model with another model, or the fidelity of a model to modelled phenomena [5]. In the context of the current case study, homomorphism was not evaluated since

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Variable	Value				
Approach	Qualitative	Quantitative			
Artifact focus	Technical	Organizational	Strategic		
Artifact type	Construct	Model	Method	Instantiation	Theory
Epistemology	Positivism	Interpretivism			
Function	Knowledge function	Control function	Development function	Legitimization function	
Method	Action research	Case study	Field experiment	Formal proofs	
	Controlled experiment	Prototype	Survey		
Object	Artifact	Artifact construction			
Ontology	Realism	Nominalism			
Perspective	Economic	Deployment	Engineering	Epistemological	
Position	Externally	Internally			
Reference point	Artifact against research gap	Artifact against real world	Research gap against real world		
Time	Ex-ante	Ex post			

Fig. 4. Variables and values for the evaluation of DSR artifacts [14].

the focus on designing the artifact was to have it as a tailor-made solution to a specific requirement and it was not compared to other existing models or solutions.

Criterion 4: Consistency - consistency in this context refers to internal consistency as asserted by Aier and Fischer [19] that in the context of DSR, the aim is to have each element of a design theory be consistent with itself. A consistent system of constructs is the common basis for all design theory elements, and thus there should be an adequate definition of all constructs used within the design. In the current study, this was ensured by using consistent terminology and the definition of all the relevant design terminologies. This was important since the DSR approach is not commonly used in radiography or the medical field.

In the current case study, the clarity, style, and level of detail criteria were not evaluated in the structural dimension. Instead, a framework (Fig. 4) proposed by Cleven et al. [14] was used to corroborate the adequacy of the evaluation approaches used.

The areas highlighted in green in the above figure indicate the approach applied in the current case study and are summarised below:

- ***Approach*** - a combination of quantitative and qualitative approaches was used, with the qualitative evaluation approach focusing on the value of the artifact while the quantitative evaluation allowed the quantification of the usability of the artifact [14].
- ***Artifact focus*** – technical and strategic evaluations were performed, since the focus on the artifact was about its design (technical), while the artifact had to be aligned to the strategy of the environment for which it was designed (strategic).
- ***Artifact type*** - the evaluation was that of an instantiation since it was based on the realization of the construct and model. Instantiation is the realization of an artifact in an environment and demonstrates the feasibility of the utility of the artifact [3,14].
- ***Epistemology*** - the evaluation was based on both the positivist and interpretive stance since, apart from knowing through making, it used both quantitative and qualitative approaches in evaluating the artifact.
- ***Function*** – the evaluation focused on the development and legitimization functions.
- ***Method*** - the evaluation in the current study was both quantitative (survey approach i.e. SUS test) and qualitative (action research approach).
- ***Object*** - the evaluation focused on the artifact itself rather than the design process.

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- ***Ontology*** **–** the evaluation corroborated the description of realism which asserts that realism is the tendency to view or represent things as they are with the belief that objects are natural. Since the evaluation was based on a combination of the quantitative and qualitative approaches, it allowed the representation of the artifact in its real current form, which matches well with the concept of ontology, i.e. what is real and not.
- ***Perspective -*** the deployment perspective was used, and it considers the comprehensibility and acceptance aspects of implementing and using artifacts. The focus of the evaluation was on the utility of the artifact, i.e. whether it was deployable in line with the objectives of the study.
- ***Position -*** the evaluation had both internal and external positions since it was evaluated by non-designers using the SUS, and it was also evaluated by the research team involved in the design of the artifact.
- ***Reference point -*** the artifact's design was for a specific utility to address a particular research gap, the evaluation, therefore, had to be against the specific research gap.
- ***Time*** **–** since the evaluation was done prior to the artifact being implemented on a full scale, the evaluation was ex-ante [5].

Direction for future research

The DSR methodology has not yet received wide use in the MRSE. This methodology has the potential to enhance research in both MRSE and the health sciences as a whole. This is important in light of artificial intelligence and other technological developments gaining wider use in the discipline. This methodology could be used in the following areas:

- Design of software for various uses e.g. dose optimization tools, educational tools, etc.
- Design of 3D printed objects as an artifact for educational use (e.g. phantom development, quality control tool, etc.
- Design of artificial intelligence-related artifacts.

Further, it could be used to corroborate other research methodologies like educational design research.

Conclusion

DSR is continuing to gain widespread use in disciplines beyond information systems, such as health sciences. This paper has demonstrated the application of DSR in the MRSE environment in the evaluation of an artifact that was designed as a tailor-made solution for training radiography students in chest pattern recognition. Rigorous evaluation approaches can be applied in DSR as demonstrated in this paper. Further, we have highlighted that, in the DSR context, the focus on evaluation is not about getting the artifact to work as expected but rather being able to provide feedback to another round of suggestions using the additional information gained in the construction and testing of the artifact. It is envisaged that this paper will contribute to the framework of considerations to be made in choosing the appropriate evaluation approach for design-based projects, and will be a suitable guide to researchers using this research approach.

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